Metallogenic Studies, Southeastern Cape Breton Island

A.S. Macdonald

Paper 89-1

Nova Scotia

Department of Mines and Energy

Honourable Jack MacIsaac
Minister

John J. Laffin, P.Eng., FEIC
Deputy Minister

Halifax, Nova Scotia
1989

90-00392/

A. S. Macdonald

Department of Geology
Acadia University
Wolfville, Nova Scotia
B0P 1X0

TABLE OF CONTENTS

	Page
ABSTRACT	1
ACKNOWLEDGMENTS	3
INTRODUCTION	5
PART 1: MARION BRIDGE AREA	
Introduction	7
Stratigraphy	7
Lower Cambrian(?) Succession	7
Middle to Upper Cambrian Succession	10
Structure	11
Metamorphism	13
Mineralization	14
Petrographic Features of Mineralization	19
Gangue Minerals	21
Type and Age of Mineralization	22
PART 2: GABARUS BAY AREA	
Introduction	27
Lithological Descriptions	27
Fourchu Group	27
Younger Intrusive Rocks	34
Grantmire Formation (?)	35
Structure	35
Ductile Deformation	35
Brittle Deformation	37
Metamorphism	39
Petrochemistry of Volcanic and Related Intrusive Rocks	39
Mineralization	42
Deep Cove	44
Irish Brook Occurrences	48
Occurrences South of Gabarus Bay	50
MacIntyre Lake	52
PART 3: STIRLING AREA	
Introduction	57
Lithological Descriptions	58
Stirling Volcanic Belt (Fourchu Group ?)	58
Sedimentary Cover Rocks (Kelvin Lake Formation)	70
Structure	72
Ductile Deformation	72
Brittle Deformation	76
Metamorphism	77
Petrochemistry of Volcanic and Related Intrusive Rocks	81
Mineralization	83
Stirling Mine Area Mineralization	83
Other Occurrences of Mineralization	84

PART 4: SUMMARY AND CONCLUSIONS 89

Comparison of the Fourchu and Stirling Volcanic Belts 92

REFERENCES 95

LIST OF FIGURES

Figure 0-1. Generalized geological map showing main areas of study and locations of metallic mineral occurrences 5

Figure 1-1. Geological map of Marion Bridge area ..... Map Pocket

Figure 1-2. Detailed geological maps.
a. Blue Mountain 8
b. French Road showings 9

Figure 1-3. Summary of structural data from Trout Brook area 12

Figure 1-4. Summary of structural data from Blue Mountain - French Road prospect 13

Figure 1-5. Petrographic features of hornfels, calc-silicate hornfels, fels, and porphyry dykes of the Blue Mountain - French Road area.
a. Spotted cordierite-biotite hornfels with quartz-sulphide veinlet 15
b. Zoning of calc-silicate knot in hornfels (quartz hornfels through epidote-rich zone to diopside-sulphide-rich inner zone) 15
c. Calc-silicate fels showing skeletal, zoned grossularite and ortho-amphibole in coarse calcite matrix 16
d. Calc-silicate fels showing ortho-amphibole aggregate with fine grained disseminated sulphides (black) interstitial to zoned grossularite aggregates 16
e. Anedral sulphide concentrations (black) within grossularite-calcite matrix 16
f. Anhedral sulphide concentrations (black) in fine grained ortho-amphibole matrix, flanked (lower left) by grossularite and calcite 16
g. Feldspar porphyritic dacite dyke at 56'in diamond-drill hole #159-1 17
h. Altered feldspar porphyritic dacite dyke at 71' in diamond-drill hole #159-6 17

Figure 1-6. Calc-silicate hornfels exposed on Blue Mountain.
a. Nodular/knotted 18
b. Layered 18

Figure 1-7. Composite projection of drillholes in vicinity of old shaft, French Road. Locations of holes are shown on inset figure 22

Figure 1-8. Microscopic features of mineralization from Blue Mountain-French Road area.
a. Typical mode of occurrence of chalcopyrite (white) interstitial to grossularite 23
b. Typical fracture-filling mode of occurrence of chalcopyrite (white) and magnetite (pale grey) 23
c. Chalcopyrite (pale grey), with small pyrite inclusions (white), surrounding grossularite crystals 24
d. Molybdenite flakes (white) interstitial to zoned grossularite crystals 24
e. Pyrite (pale grey) with inclusions of twinned arsenopyrite 24
f. Lamellar intergrowth of chalcopyrite (pale grey) and cubanite (white lamellae) 24
g. Pyrrhotite (white) concentrated along bedding (displaced by slaty cleavage) in dark argillites 25
h. Partially oxidized and deformed(?) intergrowths of pyrite and arsenopyrite in cleaved dark argillites .. 25

Figure 2-1. Geological map of Gabarus Bay area ..... Map Pocket

Figure 2-2. Petrographic features of intrusive, volcaniclastic, and volcanic rocks of Fourchu Group.
a. Quartz-feldspar crystal tuff of rhyodacitic composition from Gull Cove, showing strained quartz and kinked plagioclase 29
b. Foliated felsite sheet of dacitic composition with epidotized feldspar augen and pyrite cubes (black), disseminated and fracture controlled 29
c. Foliated lithic tuff of intermediate-mafic composition 30
d. Foliated welded tuff of felsic composition 30
e. Porphyritic intermediate flow 30
f. Mafic flow 30
g. Fine grained mafic flow, amygdaloidal and flow-textured 31
h. Porphyritic mafic sheet 31

Figure 2-3. Detailed geological map showing the distribution of intrusive sheets and dykes in the vicintiy of Gabarus Harbour .. 33

Figure 2-4. Summary of structural data from Gabarus Bay area 36

Figure 2-5. Geochemical discrimination diagrams for Fourchu Group volcanic and related intrusive rocks 41

Figure 2-6. Tectonic setting diagrams for Fourchu Group mafic volcanic and related intrusive rocks 43

Figure 2-7. Drillhole location map and representative drill core sections, Deep Cove Brook, Gabarus Bay 45

Figure 2-8. Alteration of Deep Cove granite
a. Relatively fresh biotite granite 46

b,c. Highly altered granite with chloritized and sericitized biotite phenocrysts 46, 47
d. Greisenized granite with relict quartz phenocryst 47

Figure 2-9. Detailed geological map of Irish Brook pyrite-chalcopyrite showings, Gabarus Bay, Fourchu belt 49

Figure 2-10. Some microscopic features of sulphide mineralization near Gabarus Bay.
a. Pyrite cubes plus anhedral-subhedral sphalerite containing exsolved(?) blebs of chalcopyrite (Irish Brook area) 51
b. Pyrite octahedra plus anhedral magnetite-hematite (Gull Cove) 51
c. Scattered pyrite cubes with localized anhedral chalcopyrite (Gull Cove) 52
d. Coarse pyrite with rare blebs of bornite (Cape Gabarus) 52

Figure 2-11. Detailed geological map of Gull Cove pyrite showings, Gabarus Bay, Fourchu belt 54

Figure 2-12. Detailed geological map of MacIntyre Lake chalcopyrite showing (after Perusse, 1960), Fourchu belt 55

Figure 3-1. Geological map of Stirling area ..... Map Pocket

Figure 3-2. Geological map of Point Michaud area 59

Figure 3-3. Petrographic features of volcanic and intrusive rocks of Stirling Group
a. Vesicular basalt flow 60
b,c,d. Basalt, diabase and gabbro intrusive sheets 60, 61, 61
e,f. Quartz-feldspar porphyritic rhyodacite flows 61, 61
g. Quartz-feldspar augen schist (rhyodacite flow or crystal tuff?) 62
h. Feldspar porphyritic dacite 62

Figure 3-4. Summary of drill core data from Stirling area 64

Figure 3-5. Petrographic features of epiclastic and carbonate rocks of Stirling belt.
a,b. Thin bedded siltstones showing slaty cleavage, minor euhedral pyrite (black) with pressure shadows 68
c,d. Volcanic wackes (c) with large embayed quartz clast (d) 69, 69
e. Fine grained dolostone containing sparse quartz grains 69
f. Sheared pyritic (black) dolostone 69
g. Carbonate schist containing dolomite, calcite, quartz and minor talc. Deformed pisolitic(?) dolostone 70

Figure 3-6. Summary of structural data from Stirling belt 74

Figure 3-7. Detailed geological map of Caledonia Road pyrite showing, Stirling belt 75

Figure 3-8. a. Location and geological setting of Michaelson and Loch Lomond showings, Stirling belt 78

b. Detailed geological map of Loch Lomond pyrite-sphalerite showing, Stirling belt 79

Figure 3-9. Geochemical discrimination plots for Stirling volcanic and related(?) intrusive rocks 80

Figure 3-10. Tectonic setting diagrams for Stirling mafic and intrusive rocks 82

Figure 3-11. Taylors Brook pyrite showing, Stirling belt 85

Figure 3-12. Some microscopic features of mineralization in rocks of the Stirling belt.

a,b. Fine-grained framboidal pyrite with scattered pyrite cubes. Latter also contains fine anhedral sphalerite. (a. from Collins Point, Point Michaud; b. from Caledonia Road, north of Stirling) 87, 87

c. Coarse inclusion-filled pyrite from Loch Lomond showing 88

d. Pyrite enclosed by sphalerite which contains fine chalcopyrite blebs (Loch Lomond showing) 88

LIST OF TABLES

Table 1-1. Stratigraphy of the Marion Bridge study area 10

Table 1-2. Summary of exploratory diamond-drilling in Blue Mountain - French Road area done during 1975-1977 by St. Joseph Explorations Limited 20

Table 2-1. Comparison of minor structures recognized in Gabarus and Louisbourg areas 38

Table 2-2. Geochemical analyses of volcanic and related intrusive rocks of the Fourchu belt 40

Table 2-3. Results of emission spectrographic scans of selected pyritic mineralization from Gabarus Bay and vicinity 53

Table 3-1. Geochemical analyses of volcanic and related intrusive rocks of the Stirling belt 63

Table 3-2. Results of emission spectrographic scans of selected pyritic mineralization from the Stirling belt 86

Table 4-1. Summary and comparison of geological relationships among the three areas studied 89

Table 4-2. Volcanic rock geochemistry: background values for Cu, Pb, Zn and S 91

Table 4-3. Comparison of the Stirling and Fourchu belts 93

ABSTRACT

Geological mapping and petrological studies were conducted in southeastern Cape Breton Island in the vicinities of three different polymetallic sulphide deposits in order to define the geological, spatial and temporal controls on their occurrence and to assess the exploration potential of this part of Cape Breton Island.

In the French Road - Blue Mountain area, south of Marion Bridge, contact metamorphosed argillite and siltstone of Early to Middle Cambrian age host Fe-Cu-Zn-Mo-Bi skarn mineralization and overlapping but more dispersed Fe-Pb-Zn veins and disseminations. Within the contact aureole, the host rocks are mainly cordierite-biotite hornfels, locally intruded by altered granitic porphyry dykes which are believed to be Devono-Carboniferous in age. Outside the aureole, the rocks are regionally unmetamorphosed, although they are folded and cleaved. The mineralization is contact metasomatic to hydrothermal in type, with the skarn mineralization having replaced calc-silicate layers and knots which are apparently conformable with bedding in the enclosing hornfels.

In the Gabarus Bay area, rocks of the Late Hadrynian Fourchu Group (*sensu stricto*) host the Cu-Mo-Bi-Ag-mineralized Deep Cove granitic stock and sporadic minor Cu-bearing pyritic occurrences. Pyroclastic rocks, which are mainly air-fall and debris-flow deposits, predominate over volcanic flow rocks. Geochemical studies indicate that the flows are of wide compositional range and are transitional from tholeiitic to calc-alkalic in character. All the rocks are relatively homogeneously deformed with a strong pervasive S_1 foliation. Metamorphic grade is lower greenschist facies. At Deep Cove, the Cu-Mo-Bi-Ag vein and disseminated mineralization is associated with a granite porphyry stock and related dykes of Devono-Carboniferous age and is localized within tabular alteration zones of greisen or K-feldspar enrichment and(or) in quartz-calcite vein swarms, some of which have been affected by strong east-west shearing. The minor Cu-bearing pyritic vein and disseminated occurrences which are common in the Fourchu Group around Gabarus Bay are epigenetic in character and may represent weak distal mineralization related to the Deep Cove event.

In the Stirling area, Late Hadrynian rocks of the Stirling belt, Fourchu Group (*sensu lato*), are host to exhalative volcano-sedimentary Zn-Pb-Cu-Ag-Au mineralization at Stirling and to widespread related minor Zn- and Cu-bearing pyritic occurrences. Waterlain pyroclastic and epiclastic rocks are abundant and locally contain

precipitated chert and carbonate units. Equally abundant volcanic flows are distinctly biomodal in composition and consistently calc-alkalic in character. These rocks are inhomogeneously deformed: the S_1 foliation varies widely in intensity, folding is recognized within pyroclastic and epiclastic rocks, and shearing is widespread. Metamorphic grade appears to be transitional from prehnite-pumpellyite facies into lowermost greenschist facies. Most of the mineralization in the Stirling belt is stratabound and occurs in close spatial association with chert and(or) carbonate units and with carbonatized and sericitized volcanic and volcaniclastic rocks. A possible exception is an Fe-Zn-Cu occurrence west of Stirling, which is located in a septum between dioritic and granitic phases of the Loch Lomond Pluton and appears to be contact metasomatic in type.

Favourable environments for further exploration in southeastern Cape Breton Island are the Stirling belt as a whole and any granitic intrusions of possible Devono-Carboniferous age, occurring either within the Late Hadrynian Fourchu or Stirling belts or within argillic sequences of Cambrian age, particularly where calcareous and(or) pyritic zones occur.

ACKNOWLEDGMENTS

K. White of Nova Scotia Department of Mines and Energy, together with P. Scott and D. Smeltzer, then of Acadia University and Dalhousie University respectively, all contributed substantially to the collection and compilation of the data used in this report.

C. Miller and G. Mosher of Cominco Limited kindly introduced us to the geology of the Stirling area. J. Riddell, consulting geochemist, A. Sangster of St. Joseph Explorations Limited, and H. R. Oldale of the University College of Cape Breton are all gratefully acknowledged for their co-operation in permitting access to properties or to drill core and in supplying additional information.

Quantitative and semi-quantitative chemical analyses were done by C. Cole and coworkers at CLIM Laboratories, Technical University of Nova Scotia. The Department of Geology, Acadia University, kindly allowed use of their microscopes and XRD equipment.

The paper was produced at the Nova Scotia Department of Mines and Energy over many years and through several revisions. The entire staff of the NSDME drafting department are thanked for their work on the figures and maps. Editors were D. MacDonald, H. Rand, K. Mills, J. Bates and Y. Brown and word processing was done by B. MacDonald, L. Miller, S. Saunders and S. Parsons.

INTRODUCTION

A wide variety of metallic mineral occurrences is found in southeastern Cape Breton Island within the area extending from Gabarus Bay through Stirling to Point Michaud (Fig. 0-1). The most notable of these include the polymetallic Cu-Mo prospects at Deep Cove, Blue Mountain and Gillis Mountain, the abandoned Mindamar Zn-Cu-Pb deposit at Stirling, and the Silver Mine Pb deposit at Salmon River. There are at least fifteen other small showings of largely pyritic mineralization about which there is very little published information.

This report presents the results of a metallogenic survey done in 1979 in order to describe and characterize the various types of mineralization in this area, to determine their geological settings, and hence to establish, where possible, the geological-space-time controls on their occurrence. Mapping was concentrated in three main areas: Marion Bridge, Gabarus Bay and the Stirling belt (Fig. 0-1). Other occurrences in the region falling outside of these main areas were, with several exceptions, also examined and sampled.

Work done in the Salmon River area as part of this survey has been written and presented as an M.Sc. thesis (Scott, 1980). Neither the Gillis Mountain prospect nor the Mindamar deposit are directly described in this report, as both of these have also been the subjects of M.Sc. theses by O'Beirne (1979) and Miller (1979), respectively.

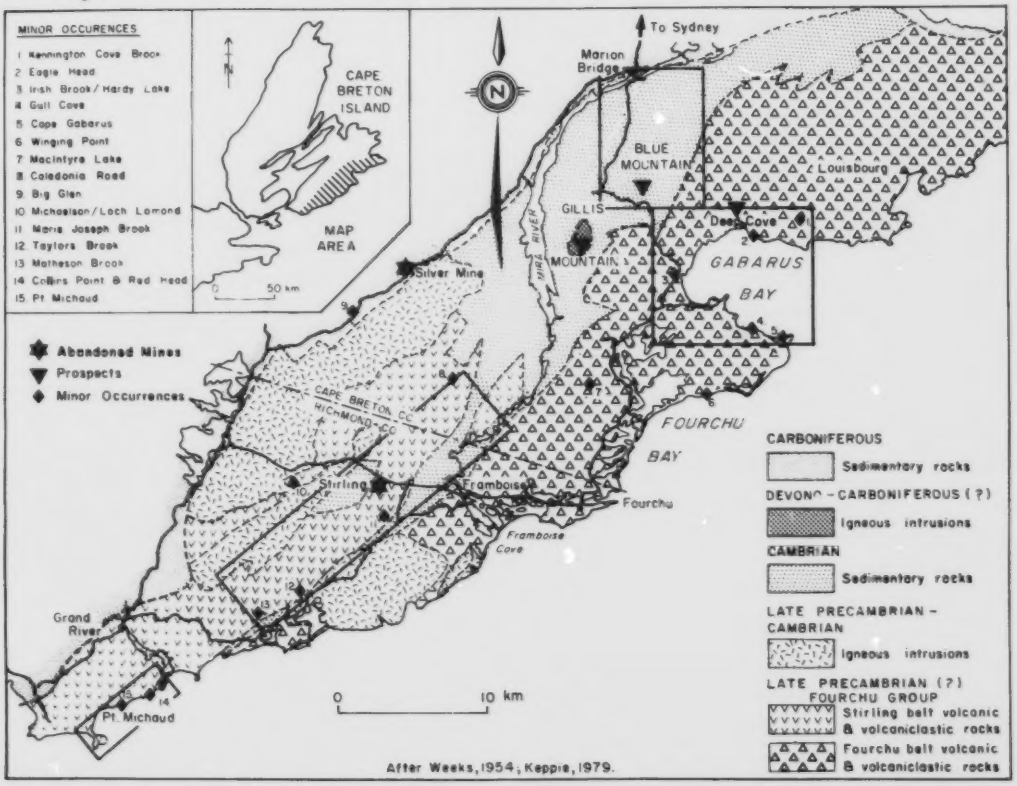


Figure 0-1. Generalized geological map showing main areas of study and locations of metallic mineral occurrences.

PART 1: MARION BRIDGE AREA

INTRODUCTION

The Marion Bridge area (Fig. 0-1) was selected for study because it includes the Blue Mountain - French Road polymetallic prospect and related occurrences which are spatially associated with contact metamorphosed Cambrian sedimentary rocks. Purposes of the study were to define the distribution and grade of the metamorphic aureole, to compare the geology inside the aureole with that outside and to describe the nature and geological setting of mineralization.

An approximately rectangular area of 45 km^2 stretching south from the Mira River along both sides of Trout Brook was mapped at a scale of 1:15 840 (Fig. 1-1; in map pocket). The area is one of generally low relief (elevations rarely exceed 75 m) blanketed with drumlins and drift, except in the vicinity of Blue Mountain where a complex of low hills forms subdued crag-and-tail features reaching elevations of 90-105 m.

Orientation and asymmetry of these various glacial features indicate generally northward movements of Pleistocene ice. Exposures are generally poor and mainly restricted to stream beds and banks, except at Blue Mountain where numerous low cliffs and small slabby outcrops occur, presumably reflecting the greater resistance to erosion of the hornfelsed rocks there. Detailed mapping, at a scale of 1:4800, was done in the immediate vicinity of the Blue Mountain and French Road showings (Fig. 1-2a, b).

Previous work in the area includes regional mapping (1:63 360) by Weeks (1954) and related palaeontological and stratigraphic studies by Hutchinson (1952). The mineralization in the Blue Mountain - French Road area has also been the subject of extensive investigations by Hollinger Gold Mines (1952), Mindamar Metals (1956-1958), Dome Exploration (1953-1956 and 1968-1969) and St. Joseph Explorations Limited (1975-1977).

STRATIGRAPHY

Generally poor exposures, except in some streams which flow to the northeast mainly along strike of the rocks, create problems in interpreting and fully understanding the structure and stratigraphy of the area. Similar problems were presumably encountered by Hutchinson (1952) and Weeks (1954) whose geological maps show the structure of the area to be a simple large syncline trending uniformly north-northeast as far as the Mira River. In this study the main lithological units were found to be more complex than previously shown.

LOWER CAMBRIAN(?) SUCCESSION

Morrison River Formation

Only a few outcrops of the Morrison River Formation (Table 1-1) were observed, in the vicinity of the Bengal Road (Fig. 1-1). They consist primarily of coarse polymictic conglomerate composed of subangular metavolcanic pebbles and rounded pebbles of grey quartzite and vein quartz in a coarse quartz arenite matrix. The relative proportions of these pebble components differ greatly, from outcrop to outcrop. The conglomerate is overall purplish-grey massive and apparently unbedded, although locally it contains beds of coarse quartz arenite. Thick current-bedded, pinkish-red to orange arkosic sandstones which contain red shale lenses and rip-up clasts occur near the

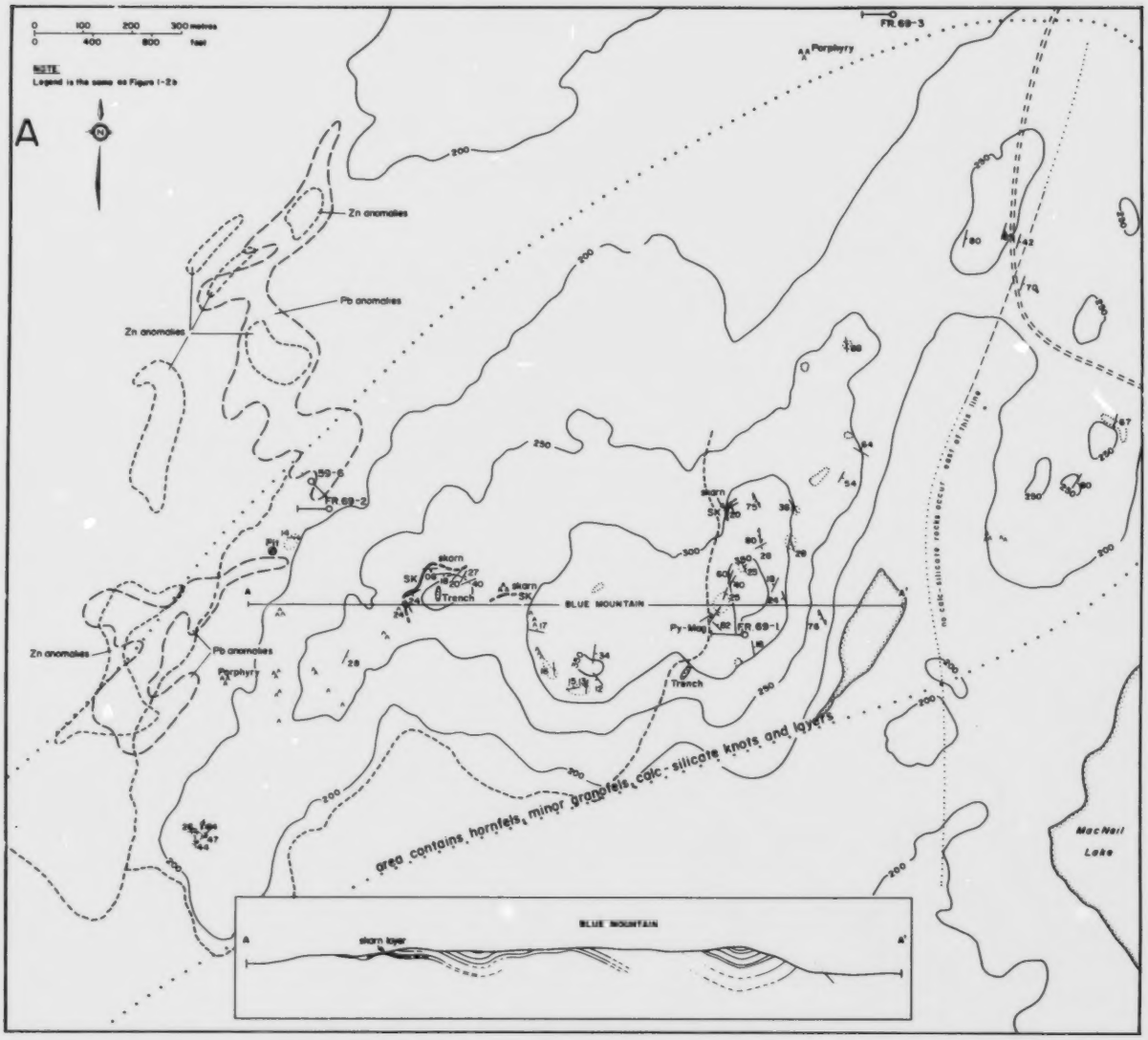
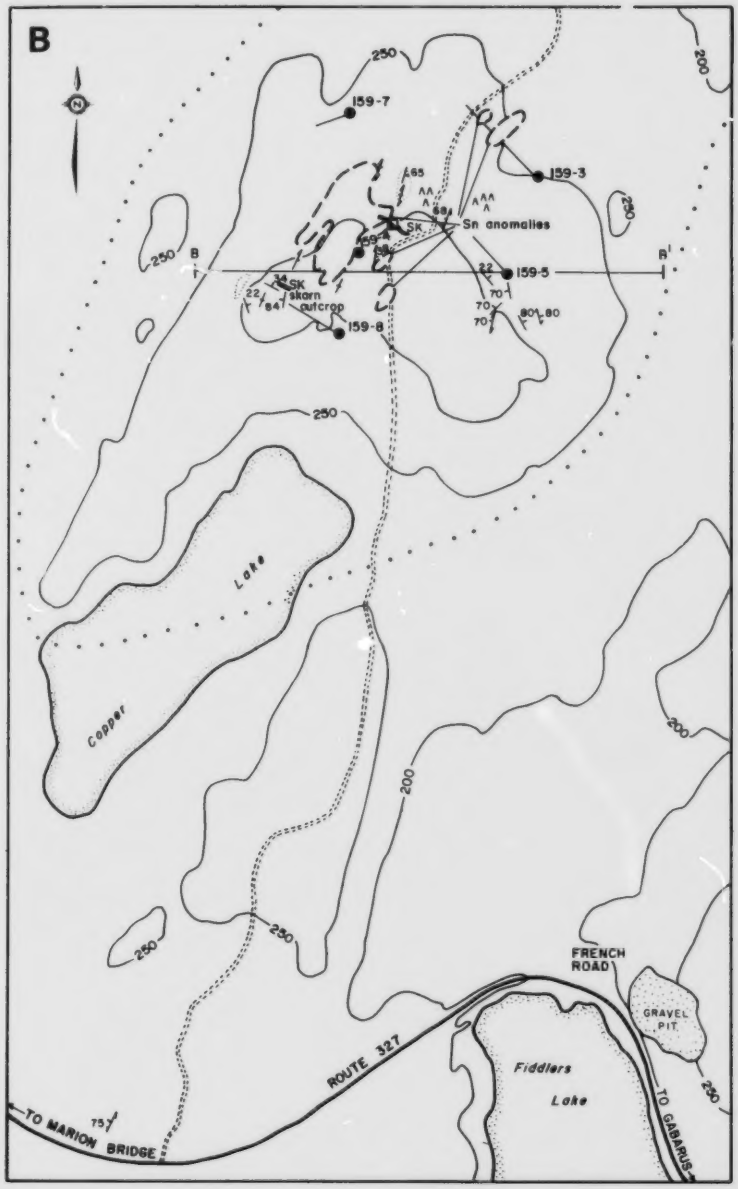


Figure 1-2. Detailed geological maps.
a. Blue Mountain.
b. French Road showings (over).
The relative location of these two maps is shown on Figure 1-1.



LEGEND

bedding
cleavage

inferred limit of contact aureole
skarn layers SK
shaft
trench, pit
outcrops
float

contour interval 50 feet

1969 drill holes, Dome Exploration Ltd.
1975-77 drill holes, St Joseph Exploration Ltd.

soil geochemical anomalies (St Joseph Exploration) Zn Pb Sn
all positions approximate

0 100 200 300 metres
0 400 800 feet

NOTE:
Legend is the same for Figure 1-2a

Table 1-1. Stratigraphy of the Marion Bridge study area.

Rock types and contact relationships	Stratigraphic units from Hutchinson (1952) & Weeks (1954)
dark grey shale, siltstone and minor thin dark grey limestone	MacNeil Formation (Upper Cambrian)
conformable contact	
grey quartz sandstone, siltstone, and dark grey shale	MacLean Brook Formation (Middle Cambrian)
..... gradational contact	
dark grey shale, minor grey siltstone and local occurrences of grey quartz sandstone, grey to pink limestone*	Trout Brook Formation (Middle Cambrian)
////////// fault contact //////////	
red mudstone and siltstone red and green siltstone, reddish arkosic sandstone and minor red shale	Canoe Brook Formation MacCodrum Formation (Lower Cambrian)
..... gradational contact	
red arkosic sandstone polymictic conglomerate, minor quartz arenite	Morrison River Formation (Lower Cambrian)

*probably representing structural inliers of MacLean Brook Formation.

assumed boundary with the overlying MacCodrum and Canoe Brook formations. The Morrison River Formation is unfossiliferous and was estimated to be about 120 m thick by Weeks (1954).

MacCodrum and Canoe Brook Formations

Rocks assigned to these two formations consist of reddish mudstone and siltstone which locally grade into greenish siltstone. Lower in the sequence, toward the gradational contact with the underlying Morrison River Formation, reddish to greyish sandstone layers and lenses also occur, apparently occupying scour channels in the mudstone-siltstone sequence. The total thickness of both formations has been estimated to be in excess of 240 m. Only the MacCodrum Formation is fossiliferous, containing Lower Cambrian trilobites (Hutchinson, 1952).

MIDDLE TO UPPER CAMBRIAN SUCCESSION

Trout Brook Formation

This formation consists of a thick sequence of dark blue-grey shale interbedded, especially toward the top of the formation, with lesser amounts of grey siltstone in beds generally less than 10-15 cm thick. The basal contact of the formation with the underlying Canoe Brook Formation has not been seen but is inferred from map distribution patterns (Fig. 1-1) to be faulted. Its upper contact is gradational into the overlying coarser clastic MacLean Brook Formation.

Thickness is probably well in excess of the 150 m minimum estimate of Hutchinson (1952) but internal folding and poor exposure make precise estimates difficult. The formation is fossiliferous and contains abundant Middle Cambrian trilobite fragments and a few inarticulate brachiopods.

Coarser grained clastic rocks, locally with associated carbonate rocks, outcrop at several locations within the area shown by Hutchinson (1952) and Weeks (1954) as being underlain by rocks of the Trout Brook Formation. These include occurrences of grey quartz sandstone and siltstone interbedded with dark shale:

(1) in the middle section of Trout Brook, north of MacKeigan Road;

(2) in the lower reaches of the first brook east of the Bengal Road, close to the inferred faulted contact with the Lower Cambrian succession (grey to pink sheared limestones are associated with this occurrence);

(3) within the Blue Mountain-French Road contact metamorphic aureole where spotted biotite and cordierite-biotite hornfels, with calc-silicate knots, lenses and layers, give way eastward to biotite hornfels and coarser quartz fels.

Presumably, all of these occurrences belong wholly, or in part, to the overlying MacLean Brook Formation, locally preserved in synclinal structures within the Trout Brook Formation (see cross-section on Fig. 1-1).

MacLean Brook Formation

This formation comprises a coarser grained facies than the underlying Trout Brook Formation from which it is gradational. It consists of light to medium grey quartz sandstone beds up to 60 cm thick, occurring in groups interbedded with medium grey siltstone (5-15 cm thick) and dark blue-grey shale in layers up to 50 cm thick. The main exposures of these rocks are in the northern part of the area, subparalleling the Mira River (Fig. 1-1). Farther south, across the main synclinal axis, these rocks are more poorly exposed. There, they appear to occupy a broad band flanking the Trout Brook Formation along its west side, and several inferred synclinal structures (previously referred to) within and along the eastern faulted margin of the Trout Brook Formation. The MacLean Brook Formation is about 300 m thick and contains inarticulate brachiopods and trilobite fragments which indicate a late Middle Cambrian age (Hutchinson, 1952).

MacNeil Formation

Occupying the core of the major syncline in the northwestern part of the area is a series of dark shale and grey siltstone with local thin beds and lenses of dark grey to black bioclastic limestone which has yielded an Upper Cambrian trilobite fauna (Hutchinson, 1952). Probably no more than 100 m of this formation are preserved here. In the type section north of the Mira River, thickness has been estimated at 300 m (Hutchinson, 1952).

STRUCTURE

Bedding is clearly visible in most of the rocks, except in the Blue Mountain - French Road area where it tends to be obscured by contact metamorphic overprinting. A cleavage (S_1), which varies from a well spaced fracture cleavage to a weak slaty cleavage, is commonly developed, especially in the shaly units of Middle Cambrian age. Where bedding is deformed into upright minor folds, this cleavage is axial planar to these folds. This

relationship is confirmed by the geometries of bedding and cleavage for the whole area, plotted in Figure 1-3a, b. These plots, together with the geological map, indicate that the Middle to Upper Cambrian rocks, at least, are folded into a series of relatively large scale upright to slightly overturned subhorizontal folds verging towards the northwest (see cross-section on Fig. 1-1). Also clear is a progressive swing in fold trends from north-northeast in the southern part of the area toward a northeast trend in the northern part of the area (Figs. 1-1 and 1-3a). It is not known whether this swing in trends, which can also be seen on regional geological maps (Weeks, 1954; Keppie, 1979) is a primary or a secondary feature.

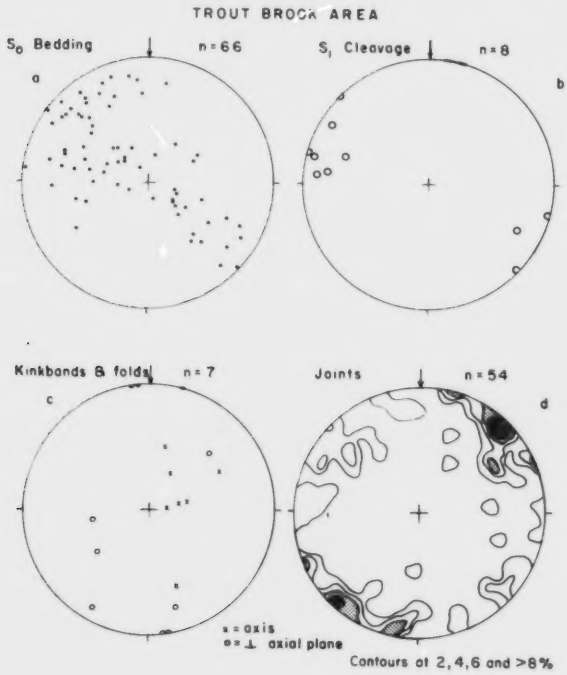


Figure 1-3. Summary of structural data from Trout Brook area.

Sparse kink bands and related minor folds, developed mainly within the more argillaceous units, provide the only evidence for any other ductile deformation in the area. These structures have east to southeast striking axial planes, plunge steeply east and north (Fig. 1-3c) and fold both bedding (S_0) and cleavage (S_1). Crude fracture cleavages or minor brecciation and quartz veining are found locally associated with these structures.

Shear zones were not observed in the Trout Brook area, although they were occasionally noted in diamond-drill core from the Blue Mountain - French Road contact aureole. There is also an apparent lack of faulting in the area, probably due to the generally poor exposure and relatively monotonous lithologies. However, a major north-south fault does appear to exist between the Lower Cambrian and the Middle to Upper Cambrian successions as the latter apparently wedges out dramatically toward the northeast (Fig. 1-1).

The pattern of joints (Fig. 1-3d) is dominated by longitudinal and cross joints with respect to fold trends but shows considerable spread in orientation due to the overall swing in structural trends from north-northeast to northeast. Several other sets of lesser joints also occur, notably north-south, north-northwest to south-southeast and east-northeast to west-southwest (Fig. 1-3d). A very similar pattern exists within the contact metamorphic aureole in the Blue Mountain - French Road area but is more sharply defined (Fig. 1-4c), presumably due to more abundant exposures and hence measurements.

Only rare veins of quartz occur in the general area, the few observed being less than 3 cm thick, steeply dipping and striking south-southeast or east-northeast. In comparison, within the contact aureole, quartz veins (up to 10-15 cm thick) are relatively common. They tend to occur in swarms dipping variably at moderate to steep angles and striking widely, mainly

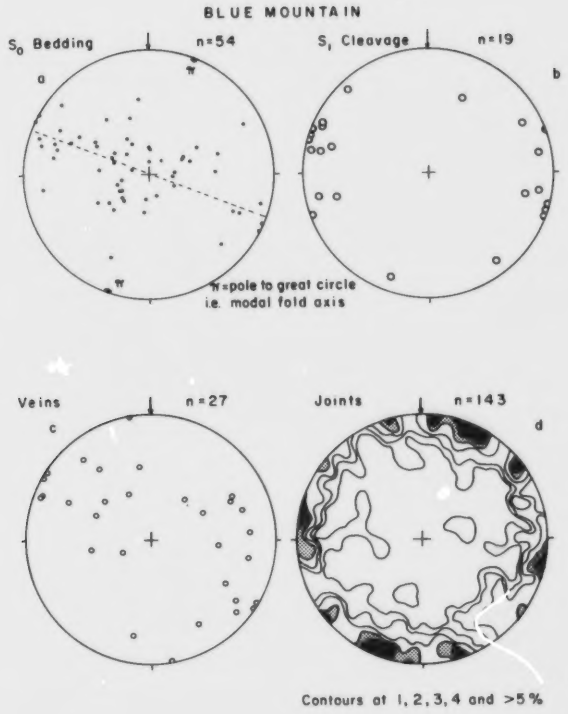


Figure 1-4. Summary of structural data from Blue Mountain-French Road prospect.

between northwest and northeast (Fig. 1-4c). In diamond-drill core, veins and veinlets of mainly quartz and calcite are common both as regular bodies and as irregular networks cementing sections of brecciated hornfels.

METAMORPHISM

The rocks in the Trout Brook area are not considered to have been regionally metamorphosed, even though an axial planar cleavage is commonly developed in the shales of the Trout Brook Formation. Where this cleavage approaches a slaty cleavage in character, the shales assume a faint phyllitic sheen on the S_1 surfaces, which is interpreted as resulting from mechanically induced preferred orientation of detrital phyllosilicates. This cleavage is not developed in the Lower Cambrian succession to the east. Thus there is no evidence in this area for attainment of the regional metamorphic threshold either laterally or vertically. However, Smith (1978) stated that the Cambrian sequence southwest of the Mira River has been regionally metamorphosed to lower greenschist facies during the Taconian or Acadian Orogeny.

The only evidence of metamorphism occurs in the Blue Mountain - French Road area where rocks presumed to be mainly Middle Cambrian in age have been contact metamorphosed by a subsurface pluton to biotite hornfels, spotted cordierite-biotite hornfels with minor medium grained biotite-quartz fels and calc-silicate fels. Common occurrences of cordierite and biotite, and of garnet and diopside in argillaceous and calcareous rocks, respectively, indicate that hornblende-hornfels facies was attained in the central part of the aureole at the levels presently exposed. The hornfels and fels give way to dark grey slaty argillites with rare calcareous lenses/layers near the inferred periphery of the aureole, coinciding approximately with the change in slope and corresponding loss of exposure toward the base of Blue Mountain. The aureole is inferred to be crudely elliptical in plan, approximately 3 km by 1 km and elongate in a northeastern direction (Fig. 1-1). Age of the contact metamorphism is not known but, as discussed later, is inferred to be Devono-Carboniferous. A K-Ar age of 357 $\pm$ 12 Ma has been obtained from biotite hornfels (S. Barr, personal communication, 1985) and supports this Devono-Carboniferous age. The only igneous rocks are dykes of dacite porphyry, 60 cm to 5.5 m thick, observed in core from two holes drilled by St. Joseph Explorations Limited (DDHs # 159-1 and 159-6; Sangster, 1977a) and reported from holes drilled by Dome Exploration Limited (Bruce, 1969). In addition, similar float material was found on the

northern and western flanks of Blue Mountain (Fig. 1-2a). These dykes are seen in thin section (Figs. 1-5g, h) to be variably altered and to consist of albite-oligoclase and rare quartz phenocrysts in a matrix of feldspar, quartz, chlorite, calcite and epidote. The age of these dykes relative to metamorphism and mineralization is not known but as they are apparently restricted to the aureole they could be related to its buried plutonic source.

MINERALIZATION

Apart from a few occurrences of disseminated pyrite in trace or very small amounts, significant mineralization occurs only in the Blue Mountain - French Road area, mainly within the contact metamorphic aureole there.

Surface showings of the mineralization are found as:

(1) oxidized, relatively sulphide-rich dump material around an old shaft at the French Road prospect;

(2) irregular disseminations and concentrations of sulphides in layers and knots of calc-silicate fels (Fig. 1-6) exposed near the old shaft and on the flanks of Blue Mountain (Fig. 1-2);

(3) minor amounts of sulphides in quartz-calcite veinlets cutting hornfels and slaty argillites.

This mineralization has been known for many years, the shaft having been sunk approximately 2 km north of French Road in 1888. Subsequent investigations by Dome Exploration in 1968-69, both in the vicinity of the shaft and farther north-northeast around Blue Mountain where other surface showings were found, involved geophysical and geochemical surveys, trenching and diamond-drilling of three holes. More recent investigations were done by St. Joseph Explorations Limited who drilled a further ten holes in the same areas as well as three holes farther south near MacIntyre Lake (Table 1-2).

Despite this exploration, the three-dimensional distribution of the mineralization is not yet well established. Best mineralized are the layers of calc-silicate fels which apparently occur in two main areas: (1) in the vicinity of the old shaft and (2) on the west flank of Blue Mountain (Fig. 1-2). However, the configuration and extent of these layers cannot be defined clearly. The enveloping knotted calc-silicate hornfels are much more widely distributed, but the percentages of calc-silicate knots and lenses in these hornfels vary up to 30%. Consequently the mineralization, which has only partially replaced the cores of the knots and lenses, is erratically distributed.

The most intensive drilling in the area was done by St. Joseph Explorations Limited in the vicinity of the old shaft (Fig. 1-2b). The data from these drillholes have been projected by the author onto a single plane perpendicular to the average fold axis in the area (Fig. 1-4a) on the assumption that distribution of favourable host rocks is one of the important factors controlling mineralization. This projection (Fig. 1-7) shows several bands of knotted calc-silicate hornfels (Fig. 1-6a) up to 70 m thick, within which and adjacent to which occur thinner layers of calc-silicate fels, up to 4 or 5 m thick (Fig. 1-6b). These are all contained within an envelope of cordierite-biotite-quartz hornfels (Fig. 1-5a) which grades upward and westward into slaty argillite. Some of the apparent repetition of the calc-silicate units could be explained by mesoscopic folding which is indicated

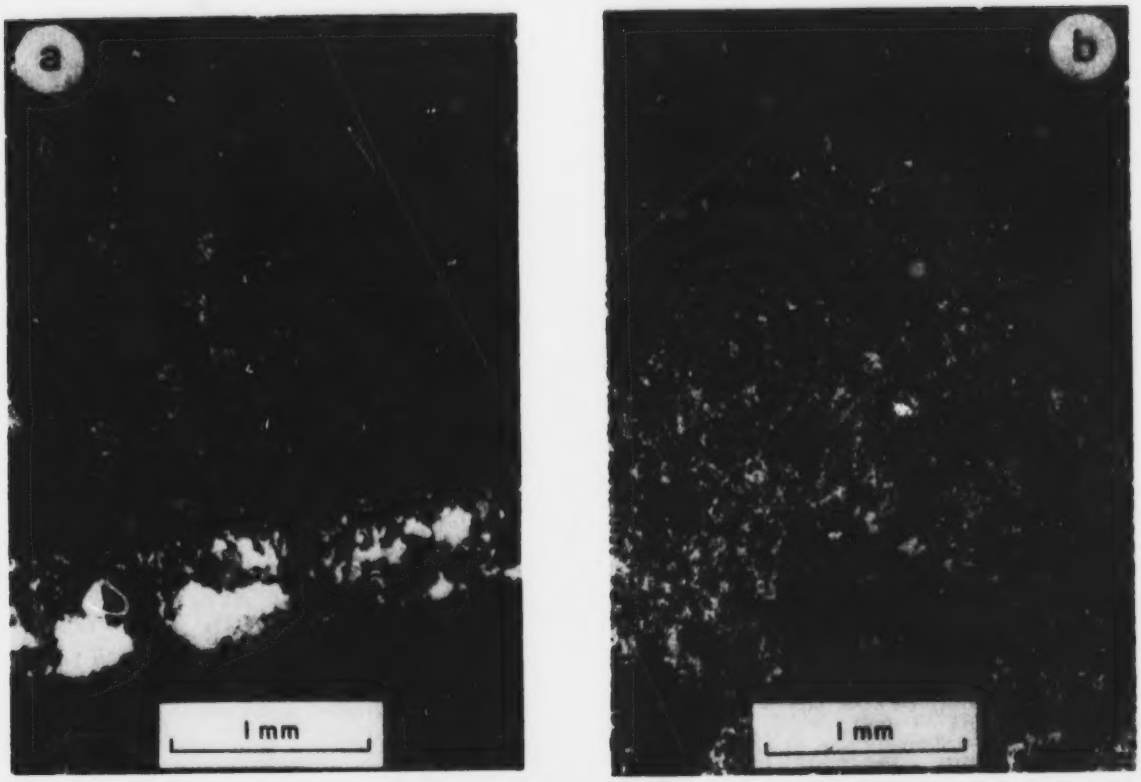
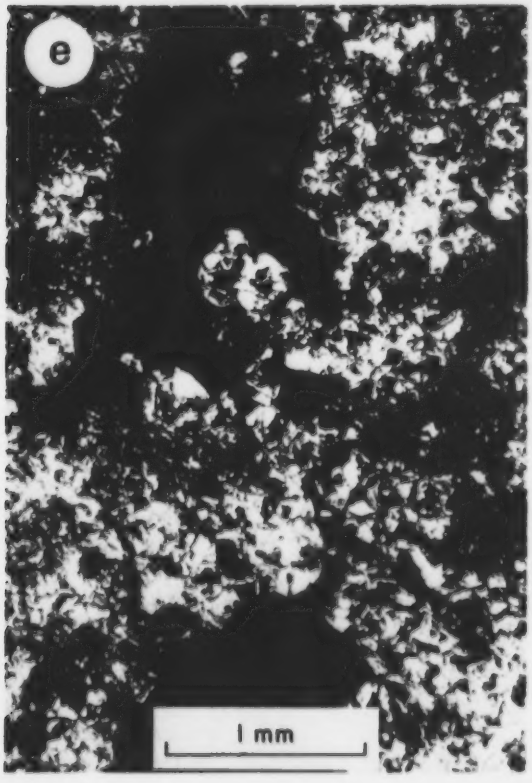


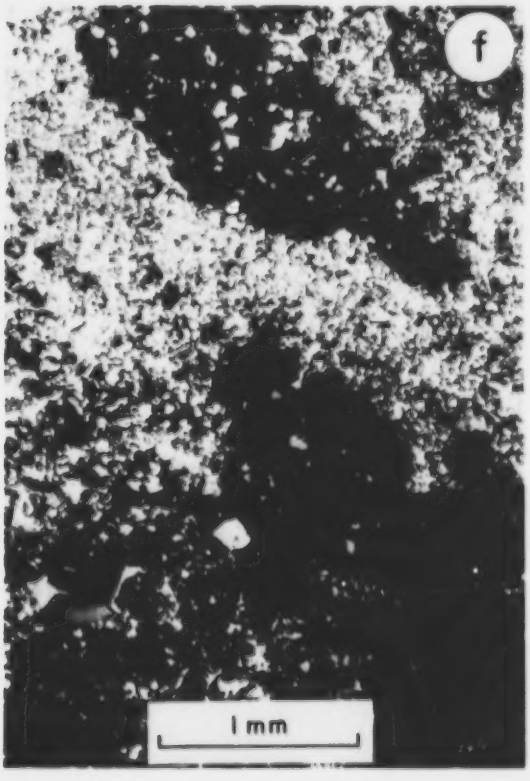
Figure 1-5. Petrographic features of hornfels, calc-silicate hornfels, fels, and porphyry dykes of the Blue Mountain-French Road area.

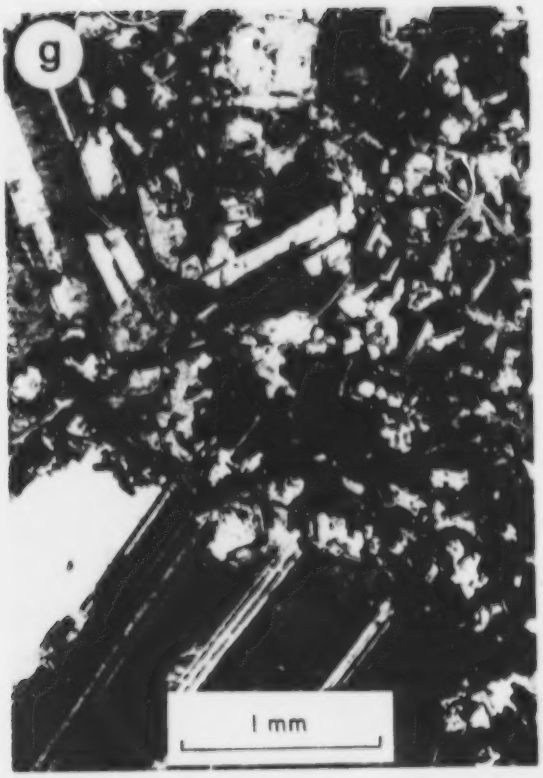
a. Spotted cordierite-biotite hornfels with quartz-sulphide veinlet.
b. Zoning of calc-silicate knot in hornfels (quartz hornfels through epidote-rich zone to diopside-sulphide rich inner zone).
c. Calc-silicate fels showing skeletal, zoned grossularite (gross) and ortho-amphibole (amph) in coarse calcite (cc) matrix (over).
d. Calc-silicate fels showing ortho-amphibole aggregate with fine grained disseminated sulphides (black) interstitial to zoned grossularite aggregates (over).
e. Anedral sulphide concentrations (black) within grossularite-calcite matrix (over).
f. Anhedral sulphide concentrations (black) in fine grained ortho-amphibole matrix, flanked (lower left) by grossularite and calcite (over).
g. Feldspar porphyritic dacite dyke at 56'in diamond-drill hole #159-1 (over).
h. Altered feldspar porphyritic dacite dyke at 71' in diamond-drill hole #159-6 (over).

c
1 mm

d
1 mm


e
1 mm


f
1 mm



by bedding-cleavage relations observed in nearby surface outcrops (Fig. 1-2, 1-4a, b).

Cutting across the hornfels and associated calc-silicate rocks in the drillholes are a number of zones of brecciation (up to 4 m thick) cemented by quartz-calcite veinlets and rare thin chlorite seams. Some of the veinlets have been sheared to powdery or clay-like gouge and any contained sulphides have been smeared out into thin films. From these it can be concluded that veining and associated mineralization were accompanied, and to some extent followed, by localized brittle deformation.

The bulk of the mineralization, observed in drillholes, in the old shaft area and elsewhere, is most closely associated with calc-silicate minerals occurring in isolated knots, coalesced knots and concentrated layers (Fig. 1-6).

The calc-silicate knots are invariably zoned ovoid masses, 2 to 5 cm across, consisting of (1) an outer cherty, siliceous zone which is actually a reaction zone depleted in phyllosilicates; generally followed inwards by (2) an epidote-rich zone; and then (3) a diopside (or actinolite) ± quartz ± calcite ± sphene(?) core containing disseminations or anhedral concentrations of pyrrhotite and lesser chalcopyrite (Fig. 1-5b).

The layers of calc-silicate fels include rocks greenish, greyish or brownish in colour, streaky to mottled or granular in texture, and fine to medium in grain size. The heaviest concentrations and widest varieties of sulphides appear to be associated with

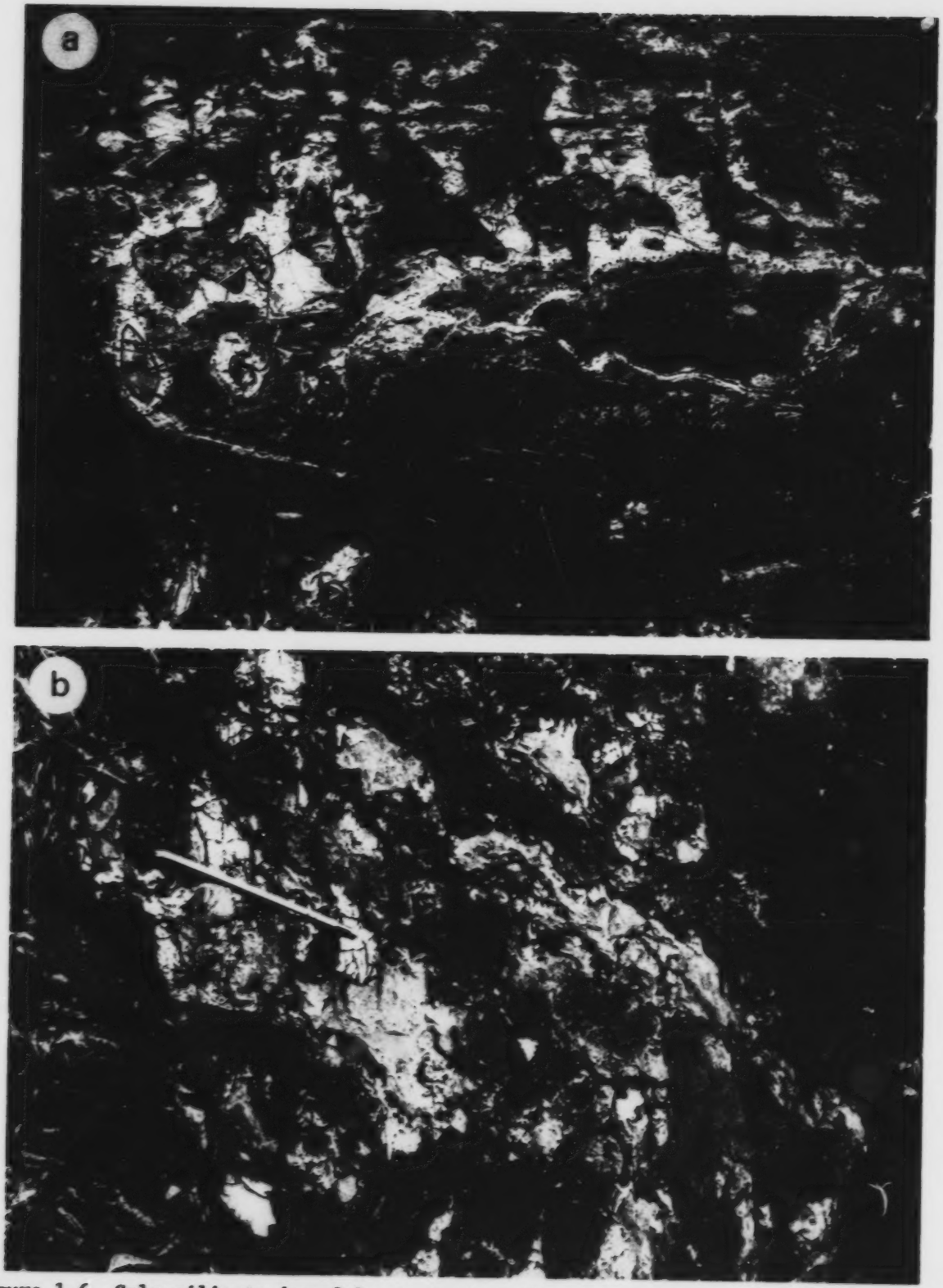


Figure 1-6. Calc-silicate hornfels exposed on Blue Mountain; (a) nodular/knotted; (b) layered.

granular grossularite-rich rocks in which the sulphides are interstitial to and poikilitically enclose idioblastic, strongly zoned grossularite (Fig. 1-5c to f). The most common calc-silicate assemblages are:

(1) grossularite (zoned, anisotropic) ± calcite ± quartz ± epidote ± ortho-amphibole

(2) garnet (isotropic) ± diopside ± calcite

(3) quartz ± epidote ± ortho-amphibole

(4) quartz + epidote ± calcite.

Accessory minerals include plagioclase, scapolite, idocrase, cordierite, sphene, fluorite and tourmaline. From their patchy distributions, commonly interstitial habits and occurrences in seams and veinlets, it is concluded that the coarse grained quartz and calcite, ortho-amphibole, epidote, fluorite and tourmaline are gangue minerals introduced essentially synchronously with the sulphides.

Other more isolated diamond-drill holes (Table 1-2), located on geochemical-geophysical targets in the vicinity of Blue Mountain and MacIntyre Lake, intersected mainly spotted cordierite-biotite and biotite hornfels with only local, sparse developments of calc-silicate knots and thin lenses, or dark grey slaty argillites. Mineralization in these rocks consists of very fine grained disseminations of pyrrhotite and lesser pyrite parallel to bedding and locally parallel to cleavage (Fig. 1-8g, h) and of fine- to medium-grained pyrite, pyrrhotite, sphalerite and galena in fractures and in quartz calcite veinlets. The veinlets rarely exceed a few centimetres in thickness and are either sparsely distributed or concentrated as localized stockworks cementing short sections of breccia (usually 15-60 cm, rarely several metres in thickness). Locally the veinlets and fracture fillings may be sheared to powdery or clayey gouge with smeared sulphide films.

PETROGRAPHIC FEATURES OF MINERALIZATION

The mineralization is polymetallic in character and superficially appears to occur in two main elemental associations:

(1) Fe-Zn-Pb in hornfels and slaty argillite.

(2) Fe-Cu-Zn-Mo-Bi in calc-silicate fels and in calc-silicate knots in hornfels.

Such apparently discrete associations suggest the possibility that the mineralization is actually polygenetic (Chatterjee, 1977). Equally, however, there appears to be sufficient overlap between these associations in both mineralogy and style to suggest that they are cogenetic and the products of mineralogical zoning.

Fe-Pb-Zn Association

Mineralogically, this association consists mainly of pyrite with intergrown arsenopyrite, pyrrhotite, lesser sphalerite and galena and rare chalcopyrite occurring in a variety of open-space and replacement habits within dark grey hornfels and slaty argillites:

(1) fine- to medium-grained aggregates in quartz-calcite veinlets and localized stockworks (cementing breccias);

(2) fine grained films on joint surfaces;

(3) very fine grained disseminations parallel to bedding (S_0) and to a lesser

Table 1-2. Summary of exploratory diamond-drilling in Blue Mountain-French Road area done during 1975-1977 by St. Joseph Explorations Limited.

Hole #	Location	Main Rock Types	Mineralization*
159-1	W of French Road	Dark grey slaty argillite, brecciated locally; 4 m feldspar porphyry dyke.	Po & Py disseminated parallel to S_0 and S_1, also in quartz-calcite veinlets.
159-2		Dark grey slaty argillite becoming hornfelsed with depth.	As above but also with local Gn and Sp in veinlets
159-3	near old shaft N of French Road	Dark grey hornfels changing to knotted calc-silicate hornfels with calc-silicate fels bands up to 4 m thick	(i) Po>Py>Cp in calc-silicate knots (ii) Po>Py>Cp>Sp>Asp>Mb>Bs in calc-silicate fels bands (iii) Py>Po>Sp>Gn in quartz-calcite veinlets
159-4		Mainly knotted calc-silicate hornfels with 2 calc-silicate fels bands of 2 m and 4.5 m, lesser dark grey hornfels top and bottom	
159-5		Dark grey hornfels changing to mainly knotted calc-silicate hornfels with calc-silicate fels bands up to 2 m	
159-7		Dark grey slaty argillite changing to dark grey hornfels and finally to knotted calc-silicate hornfels	
159-8		Mainly knotted calc-silicate hornfels with lesser dark grey hornfels and coarser granofels	
159-6	W side of Blue Mountain	Spotted hornfels with occasional thin calc-silicate fels bands; 1 m feldspar porphyry dyke	Py>Po disseminated and in joints; Gn>Sp>Py in quartz-calcite veinlets; Po>Cp in calc-silicate felses
158-1	NNW of Blue Mountain	Dark grey slaty argillite, brecciated locally; occasional thin calcareous bands	Py & Po disseminated parallel to S_0, also in joints and in quartz-calcite veinlets
158-2		Dark grey slaty argillite, rarely brecciated	
220-1 220-2 220-3	S of MacIntyre Lake	Grey metagreywacke, metasiltstone and white quartzite, with extensive quartz>calcite veining	Py>Cp in joints and in quartz-calcite veinlets; locally disseminated in metagreywacke

*Abbreviations: Po = Pyrrhotite, Py = Pyrite, Cp = Chalcopyrite, Gn = Galena, Mb = Molybdenite, Sp = Sphalerite, Asp = Arsenopyrite, Bs = Bismuthinite

extent cleavage (S_1) (Fig. 1-8g, h).

In a general way, the Fe-Pb-Zn association which occurs in veinlets and as fine disseminations along bedding and cleavage planes overlaps the polymetallic mineralization associated with the calc-silicate rocks and extends into more uniform slaty argillites which occur nearer the periphery of the aureole (e.g. south of MacIntyre Lake and north of Blue Mountain).

Fe-Cu-Zn-Mo-Bi Association

Mineralogically, this association consists chiefly of pyrite, arsenopyrite, pyrrhotite and chalcopyrite with minor cubanite, magnetite, sphalerite, molybdenite and bismuthinite(?). The association occurs in several habits (closely associated with calc-silicate host rocks and minerals):

(1) fine grained patchy disseminations and coarse anhedral masses within zoned calc-silicate knots and within grossularite-rich calc-silicate fels (Fig. 1-8a, c); and

(2) rare fracture fillings cutting the calc-silicate fels (Fig. 1-8b).

In the zoned calc-silicate knots, the mineralogy is dominated by pyrrhotite and chalcopyrite, whereas in the calc-silicate fels pyrite and arsenopyrite are dominant, commonly associated with lesser magnetite and localized concentrations of molybdenite and bismuthinite(?).

Pyrite and arsenopyrite are commonly intimately associated in medium grained crystalline aggregates and coarser irregular masses, the arsenopyrite occurring as euhedral inclusions or geometric intergrowths in pyrite (Fig. 1-8c). However, either mineral may also occur alone as individual euhedral crystals and more commonly as crystalline aggregates. Pyrrhotite occurs as anhedral patches commonly displaying mutual growth boundaries with chalcopyrite, but also as inclusions within chalcopyrite and pyrite. Locally, small areas of marcasite are developed within pyrrhotite. Magnetite occurs as scattered subhedral grains commonly included within chalcopyrite and pyrrhotite. Chalcopyrite forms small anhedral patches to coarse masses partially enclosing and veining pyrite (Fig. 1-8c) and locally the chalcopyrite contains lamellar intergrowths of cubanite (Fig. 1-8f). In weathered samples collected from the shaft spoil heap, minor supergene(?) alteration of chalcopyrite to neodigenite(?) and covellite has occurred along fractures and around grain boundaries. Sphalerite occurs in minor amounts as small anhedral grains displaying mutual growth boundaries with chalcopyrite and as inclusions within it. Molybdenite occurs as granular to cleaved aggregates associated with pyrite $\pm$ chalcopyrite as disseminations and veinlets in calc-silicate fels (Fig. 1-8d). Bismuthinite(?) is found as rare soft, cream-coloured isotropic material associated with chalcopyrite. Galena occurs only as rare, sparsely disseminated very fine- to fine-grained anhedra and partial cubes generally isolated or rarely adjacent to chalcopyrite.

GANGUE MINERALS

Medium- to coarse-grained quartz (containing rutile needles) and calcite are the main gangue minerals and occur as widespread vein and cavity fillings and as patchy replacement(?) of calc-silicate fels and of the cores of some calc-silicate knots. Although ortho-amphibole, partially altered to chlorite, generally occurs as fine grained aggregates with patchy distribution within calc-silicate fels

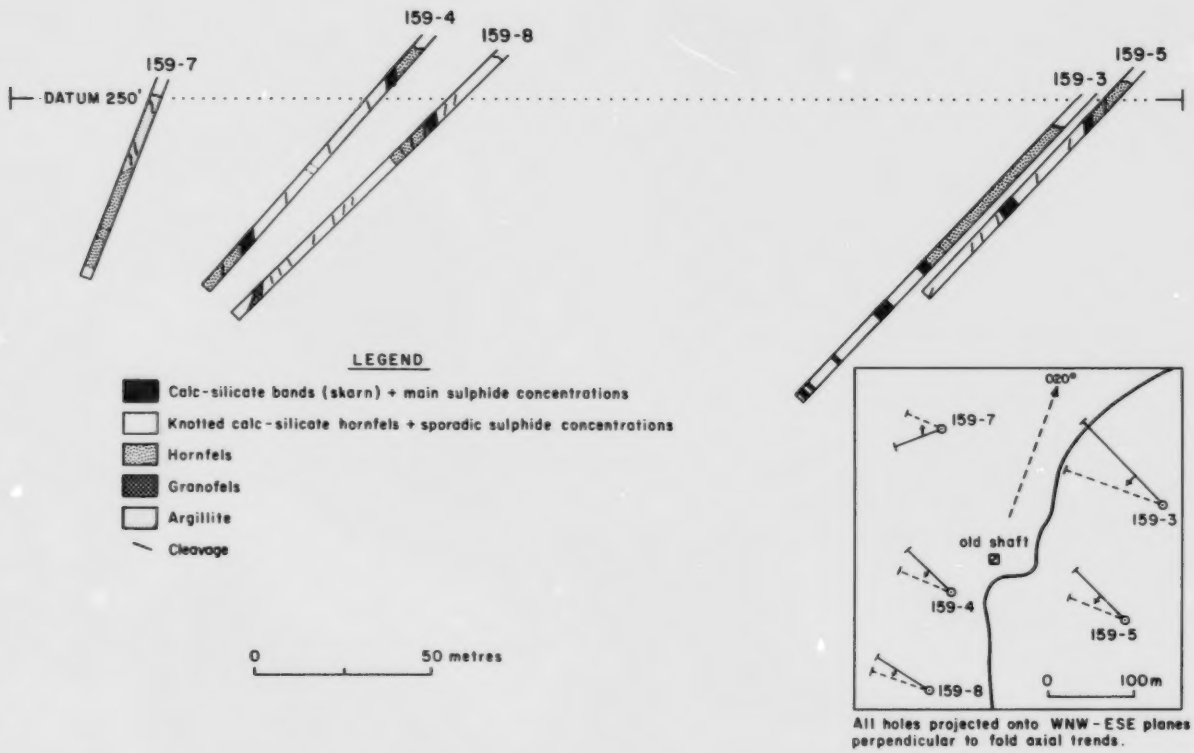


Figure 1-7. Composite projection of drillholes in vicinity of old shaft, French Road. Locations of holes are shown on inset figure.

(particularly the grossularite-rich varieties) it may also be coarse grained and closely associated with coarse quartz and calcite. Primary chlorite is found as local fillings of seams and veinlets. Black tourmaline (schorl) may also occur in some veinlets and as local fine- to medium-grained aggregates. Both habits are commonly associated with sulphides. Small amounts of fluorite, displaying anhedral interstitial habit, were also found in a few samples of calc-silicate fels.

TYPE AND AGE OF MINERALIZATION

The mineralization appears to be essentially contact metasomatic in type, given its apparent restriction to the contact aureole and its common replacement association with calc-silicate rocks. However, there are also numerous open-space fillings in quartz-calcite veins and stockworks, attesting to late-stage hydrothermal activity.

It is difficult to evaluate the relative contributions of contact metamorphic, metasomatic and hydrothermal processes to the development of the observed assemblages and textures. Quartz and calcite, together with lesser fluorite, tourmaline, chlorite and sulphides, are all demonstrably introduced. Similarly, the relatively abundant grossularite and orthoamphibole which commonly host sulphide mineralization may result from introduced materials, but they could have been formed by purely metamorphic reactions involving the calc-silicate precursor.

There is also some doubt as to the original nature of the calc-silicate rocks, both knotted and layered. Chatterjee (1977) has suggested that the latter may be metasomatized mafic

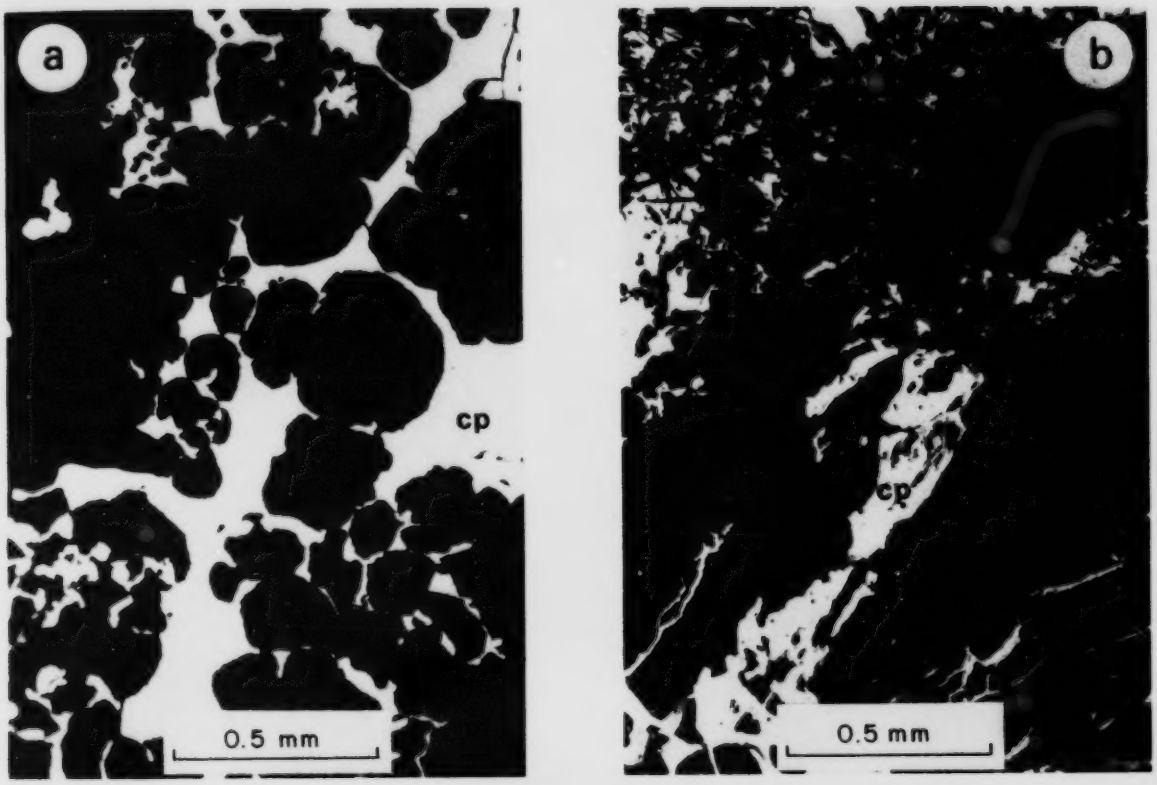
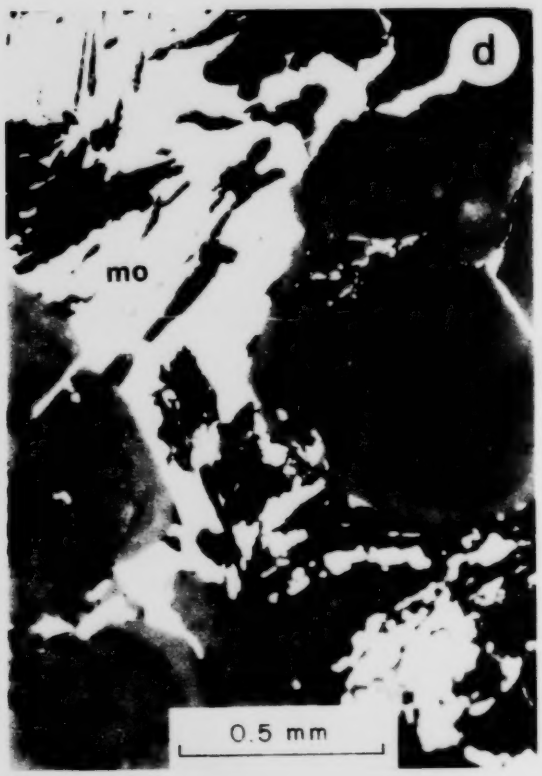
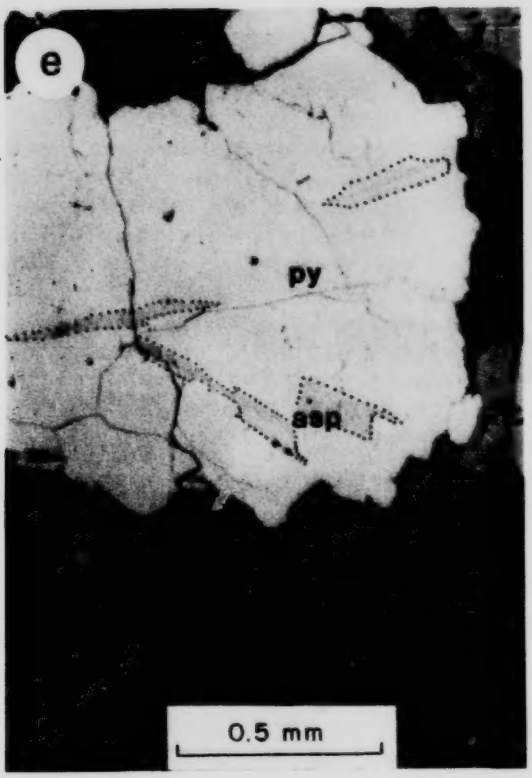


Figure 1-8. Microscopic features of mineralization from Blue Mountain-French Road area.

a. Typical mode of occurrence of chalcopyrite (cp, white) interstitial to grossularite (gr).
b. Typical fracture-filling mode of occurrence of chalcopyrite (white) and magnetite (mg, pale grey) (over).
c. Chalcopyrite (pale grey), with small pyrite (py) inclusions (white), surrounding grossularite crystals (over).
d. Molybdenite flakes (mo, white) interstitial to zoned grossularite crystals (over).

c
py
cp
0.5 mm


d
mo
0.5 mm


e
py
asp
0.5 mm

f
0.5 mm

volcanic rocks. An alternative interpretation favoured by this author is that they represent impure calcareous sedimentary-diagenetic rocks. Thin limestone beds and sparsely distributed calcareous nodules have been observed at several localities in the Cambrian sequence within a few kilometres of the metamorphic aureole, whereas no volcanic or volcaniclastic rocks have yet been recognized in the Marion Bridge area, although a felsic volcanic unit of Lower to Middle Cambrian age has been recognized west of the Mira River (Smith, 1978).

The age of contact metamorphism and mineralization at Blue Mountain is not yet known, except that it post-dates upright folding of the Cambrian strata. It seems likely that the age is Devono-Carboniferous, as indicated by a K-Ar age of 357 ± 12 Ma from biotite hornfels (S. Barr, personal communication, 1985), similar to those of the Gillis Mountain Pluton located 5 km to the southwest (Rb/Sr age = 384 ± 10 Ma; Cormier, 1979), and Deep Cove stock located 8 km to the east-southeast (Rb/Sr age = 342 ± 20 Ma; Cormier, 1972; Keppie and Smith, 1978 and K/Ar age = 387 Ma; Zentilli, personal communication, 1983). All three areas are mineralized and although the types of mineralization differ, the metallic associations present do appear to be broadly similar:

Gillis Mountain: Fe-Cu-Mo
Blue Mountain-French Road: Fe-Cu-Zn-Pb-Mo-Bi-Ag(?)-Sn(?)
Deep Cove: Fe-Mo-Cu-Pb-Zn-Bi-Ag

The only igneous rocks observed in the Blue Mountain - French Road area

are feldspar porphyry dykes of dacitic composition and although the age of these dykes relative to the contact metamorphism and mineralization is not known they petrographically resemble a fine grained feldspar porphyry phase found within the Deep Cove stock (see the bottom of DDH 79-1 on Fig. 2-7).

PART 2: GABARUS BAY AREA

INTRODUCTION

The area west and south of Gabarus Bay was selected for study because it is on strike from the Deep Cove polymetallic mineral prospect and related occurrences (Bingley, 1969; Riddell, 1973; Sangster, 1977b) and it includes a number of small Fe-Cu occurrences (Figs. O-1 and 2-1, in map pocket).

Purposes of this study were (1) detailed stratigraphic and petrologic subdivision of the Fourchu Group across one of the best available transects (the north side of Gabarus Bay is partly obscured by contact metamorphic overprinting in the vicinity of Deep Cove), (2) determination of the nature and setting of the occurrences of Fe-Cu mineralization within these rocks and (3) comparison of this stratigraphy and mineralization with those on the north side of Gabarus Bay between Deep Cove and Kennington Cove.

A narrow strip, 18 km long, extending around Gabarus Bay from Deep Cove to Cape Gabarus was mapped at a scale of 1:4800. This was extended inland from the west side of Gabarus Bay as far as Hardy Lake in order to include the Irish Brook Fe-Cu occurrence (Leslie, 1969) and additional exposures along the Marion Bridge-Gabarus road. The area mapped is primarily coastal in character with numerous long exposures, locally obscured by till banks (eroding drumlins) and interrupted by sand spits and associated lagoons. Relief behind the shoreline is relatively subdued, especially to the south of Gabarus Bay where elevation rarely exceeds 30 m, in contrast with the north side of the bay where elevation increases rapidly to about 60 m behind the shoreline. Exposures inland are generally poor except along incised streams, such as Irish Brook, and in roadcuts along the Marion Bridge - Gabarus highway.

Previous work around the west and south sides of Gabarus Bay has been limited to regional mapping (1:63 360) by Weeks (1954), a report of exploration work in the Irish Brook-Hardy Lake area (Leslie, 1969), and a geological engineering report on the Gabarus area as a potential site for a new steel plant (Oldale, 1975). In contrast, the north side of Gabarus Bay, because of the mineralization at Deep Cove, Eagle Head and Kennington Cove Brook, has been much more intensively investigated (Bingley, 1969; Riddell, 1973 and 1979; Forgeron, 1974; Chatterjee, 1976; Murphy, 1977; Sangster, 1977b). In addition, the Deep Cove deposit has been described as 'porphyry-type' and compared with similar deposits in the Appalachians (Hollister et al., 1974; Kirkham and Soregaroli, 1975).

LITHOLOGICAL DESCRIPTIONS

FOURCHU GROUP

A wide variety of metamorphosed volcanic, volcaniclastic and related intrusive rocks are exposed around the shoreline of Gabarus Bay, providing one of the better available sections across strike of the Fourchu Group. The relative percentages of intrusive, volcanic, pyroclastic-volcaniclastic and epiclastic rocks are estimated to be approximately 5%, 20%, 70% and 5% respectively. Pyroclastic and volcanic rocks thus predominate and are readily subdivided into mappable units (Fig. 2-1). The apparent repetition of these units could be due either to folding (see section on Structure), or as appears equally likely, to cyclical volcanic activity.

Volcanic Rocks

Three main volcanic units, approximately 400-600 m thick, were distinguished from west to east in the vicinities of Lever Lake, Harris Lake

and Cape Gabarus (Fig. 2-1). These are separated by thick sequences of mainly mixed volcaniclastic and pyroclastic rocks.

The volcanic units consist mainly of mafic flows with local occurrences of intermediate flows. The mafic flows are dark grey, purplish-grey or dark greenish, generally fine grained and more or less porphyritic. They are rarely vesicular or amygdaloidal and are generally uniformly massive, although locally they appear strongly flow-brecciated (e.g. at Harris Lake) or even agglomeratic (e.g. in the vicinity of Cape Gabarus). A weak internal tectonic foliation (S_1) is commonly visible, together with locally developed narrow schistose zones. Typically, the flows are strongly fractured with distinctive hematite coatings on the fracture surfaces. Locally, they are interbedded with layers and lenses of intermediate to mafic tuffs.

In thin section, they consist of plagioclase phenocrysts partially altered to epidote and sericite, mafic phenocrysts(?) crudely pseudomorphed by chlorite and(or) epidote and opaques. The matrices consist of fine grained intergranular, often flow-textured albitic plagioclase laths, chlorite, epidote and hematite or leucoxene, together with varietal quartz, calcite and pyrite (Fig. 2-2f, g). In some samples, incipient very fine grained tremolite-actinolite appears to have developed in the matrix. The plagioclase phenocrysts were found to be mostly oligoclase-andesine (An_{27-37}).

Minor amounts of intermediate volcanic rock occur as flows locally associated with the more abundant mafic flows. They are dark grey to blue-grey, sparsely porphyritic aphanitic rocks, commonly with green epidotic spots, streaks and diffuse veins. In thin section they are more or less epidotized, with highly altered plagioclase phenocrysts in matrices of plagioclase laths, granoblastic quartz, chlorite, epidote, sericite and iron oxides (Fig. 2-2e).

Pyroclastic-Volcaniclastic Rocks

Three compositional groups of lithic tuffs were distinguished in the field: felsic, felsic-intermediate and intermediate-mafic, estimated to be present in percentages of about 25%, 35% and 40% respectively. While most of the tuffs can be classed as lapilli tuffs, they vary considerably in the sizes of their contained fragments and range from ash to agglomerate. The bulk of these rocks appear to have been deposited in thick massive layers, as compositional banding and grading of the tephra are very weakly developed and can only be discerned locally. In a few localities, unconformable contacts are developed between such layers. It is thought that the tuffs include debris flows as well as air-fall deposits.

Fragment sizes are mostly 1-5 cm but may include larger blocks up to 1 m across. The smaller fragments are generally crudely ellipsoidal in shape, presumably due largely to greater flattening and stretching within the pervasive tectonic foliation.

Occasional very thick units, up to several tens of metres, of more uniformly fine grained tuffs of felsic and intermediate compositions were found to contain closely packed, strongly flattened fragments which appear welded. These tuffs are considered to be ash-flow tuffs. The sequence therefore appears to be dominated by coarser air-fall and debris-flow material but also to include a number of ash-flow units.

Felsic tuffs form two map units approximately 300 m and 1300 m thick.

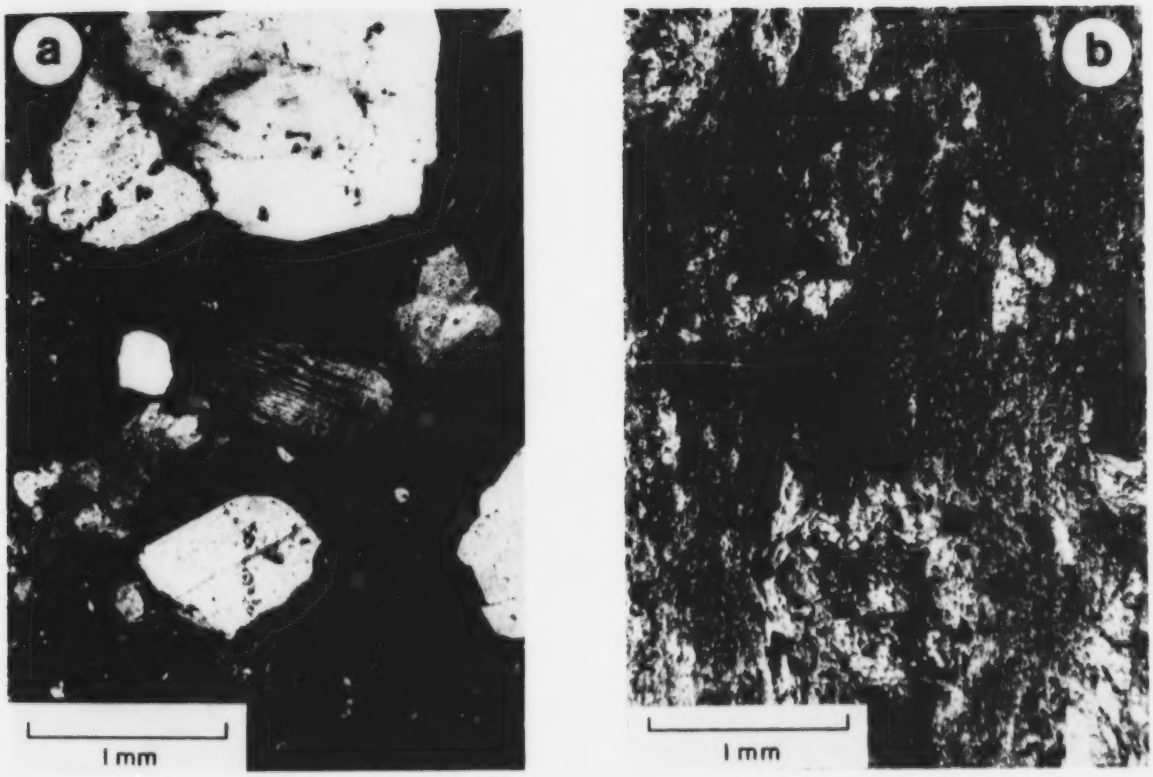


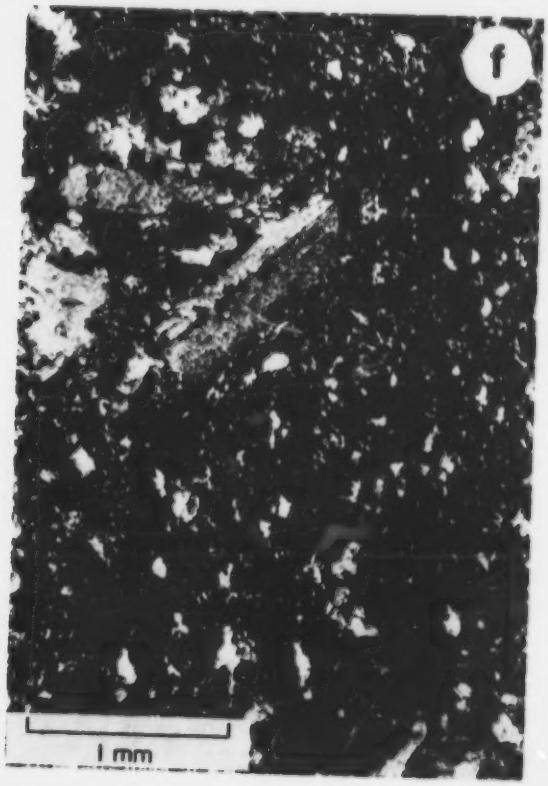
Figure 2-2. Petrographic features of intrusive, volcaniclastic, and volcanic rocks of Fourchu Group.

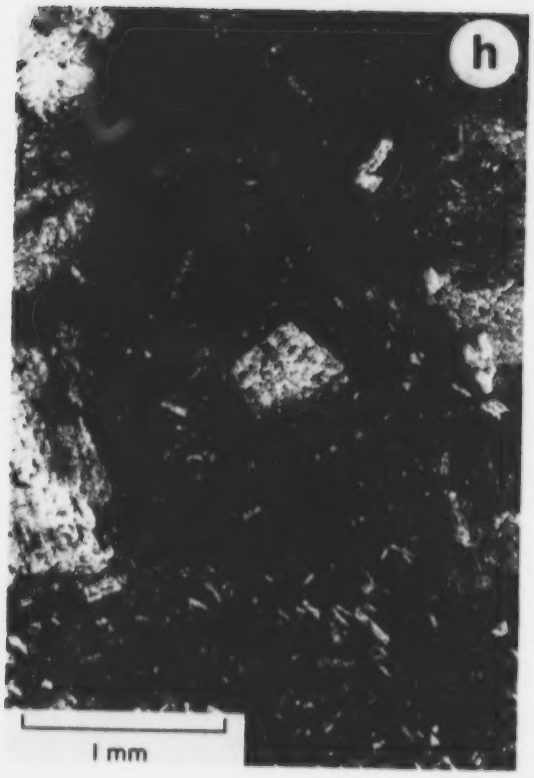
a. Quartz-feldspar crystal tuff of rhyodacitic composition from Gull Cove, showing strained quartz and kinked plagioclase.
b. Foliated felsite sheet of dacitic composition with epidotized feldspar augen and pyrite cubes (black), disseminated and fracture controlled.
c. Foliated lithic tuff of intermediate-mafic composition (over).
d. Foliated welded tuff of felsic composition (over).
e. Porphyritic intermediate flow (over).
f. Mafic flow (over).
g. Fine-grained mafic flow, amygdaloidal and flow-textured (over).
h. Porphyritic mafic sheet (over).

c
1mm

d
1mm

e
1mm


f
1mm



Typically, they are pale greenish or pinkish rocks which contain distorted lapilli of aphanitic rhyolite, aphanitic to fine grained pophyritic dacite, and white pumice (?), together with plagioclase and quartz crystals in more or less schistose matrices of quartz, feldspar, sericite, epidote and chlorite. The crystal:lithic ratio in most of these tuffs is very low, although in some it reaches 50:50. In the rarer ash-flow tuffs, similar lithic fragments and crystals, commonly together with fragments of dark vesicular aphanitic lava, occur in very closely packed, flattened arrangements (Fig. 2-2d). These ash-flow tuffs appear to occur only in the western part of the area on the west side of Gabarus Bay and along Irish Brook. Fine grained laminated ashes which contain only sparse dacitic fragments, and quartz and feldspar crystals set in more or less foliated quartzo-feldspathic matrices are locally associated with some of the felsic tuffs.

Felsic-intermediate lithic tuffs form two map units within the area, approximately 800 m and 1200 m thick (Fig. 2-1). Typically, they are medium grey-green or purple lapilli tuffs, banded to massive, occurring either in thick, relatively uniform sequences or interbedded with more felsic tuffs including ash-flow tuffs. They consist of abundant tephra of flow-textured, sparsely porphyritic dacite, together with variable amounts of quartz and plagioclase crystals in fine- to medium-grained foliated matrices rich in chlorite and epidote.

Intermediate-mafic tuffs are the most abundant of the three compositional groups occurring as several units between 300 and 500 m

thick. In Gull Cove, they form a unit flanking the Gull Cove porphyry intrusion, and on the northwest side of Gabarus Bay, they also form one or two units flanking the mafic-intermediate volcanic unit. Another unit of intermediate-mafic tuffs occurs within felsic tuffs between Gabarus and Gabarus Barachois. Typically, these are medium to dark greenish chloritic and schistose fragmental rocks containing abundant aphanitic to fine grained vesicular to amygdaloidal tephra of mafic volcanics in fine grained matrices of chlorite, epidote and oxidized magnetite together with varietal tremolite-actinolite, biotite and pyrite (Fig. 2-2c). Hematite is characteristically developed on fracture surfaces in these rocks.

A quartz-feldspar crystal tuff unit which occurs at Gull Cove is a massive, variably foliated body, cut by mafic sheets similar to those in the surrounding volcanic rocks and lithic tuffs. The unit parallels the main structural trend but has slightly chilled margins which are locally irregular and crosscutting. It is of rhyodacitic composition, slightly more felsic than, but otherwise similar in composition to, the felsite sills in the surrounding rocks. No felsic sheets were observed within the crystal tuff itself. In thin section, the tuff has a hiatal porphyroclastic texture with large strained crystals of resorbed quartz, some with sutured grain boundaries or overgrowths and altered albitic plagioclase (An_{5-10}) with small chlorite-epidote pseudomorphs after biotite(?) in a very fine grained matrix of quartz, feldspar, chlorite, sericite and hematite (Fig. 2-2a). Foliation is variably developed and the crystals are commonly strained, fractured and have developed pressure shadows.

Epiclastic Rocks

Thin beds of epiclastic material, interbedded mainly with tuffs, are found at only a few localities: on the west side of Gabarus Bay, near Rams Head, and between Gull Cove and Cape Gabarus. They are generally thinly bedded or laminated, grey, green or purple rocks locally displaying graded bedding and scour and slump structures. The bulk of the rocks are volcanic mudstones and siltstones with only a few layers and individual beds of volcanic wacke. They consist mainly of quartz, feldspar, epidote, sericite and chlorite with coarse clastic grains of subangular quartz and plagioclase.

Intrusive Rocks

Three groups of foliated meta-igneous rocks which intruded the Fourchu Group are believed to be essentially comagmatic with the volcanic and pyroclastic rocks. They comprise two suites of sills (one felsic and the other mafic) and several andesite porphyry plugs(?).

Felsite sills are widespread and locally are very closely spaced, particularly between Lighthouse Point and Rouse Point near Gabarus Barachois (Fig. 2-3). In general, they are more or less conformable with layering and schistosity (S_0-$_1$) in the host rocks, but locally they branch and crosscut irregularly. They range from a few cm to 10-20 m thick. Greenish to brownish in colour, they are typically aphanitic, fine- to medium-grained feldspar porphyritic rocks which are not obviously foliated, but are closely fractured and veined with quartz ± epidote ± hematite.

In thin section, the felsite sills display small plagioclase phenocrysts set in very fine grained foliated matrices. The plagioclase phenocrysts are usually altered to sericite and epidote, and are deformed into augen, some of which show pull-apart structures. The schistose matrices consist of quartz, feldspar, sericite, chlorite and epidote. Pale greenish-

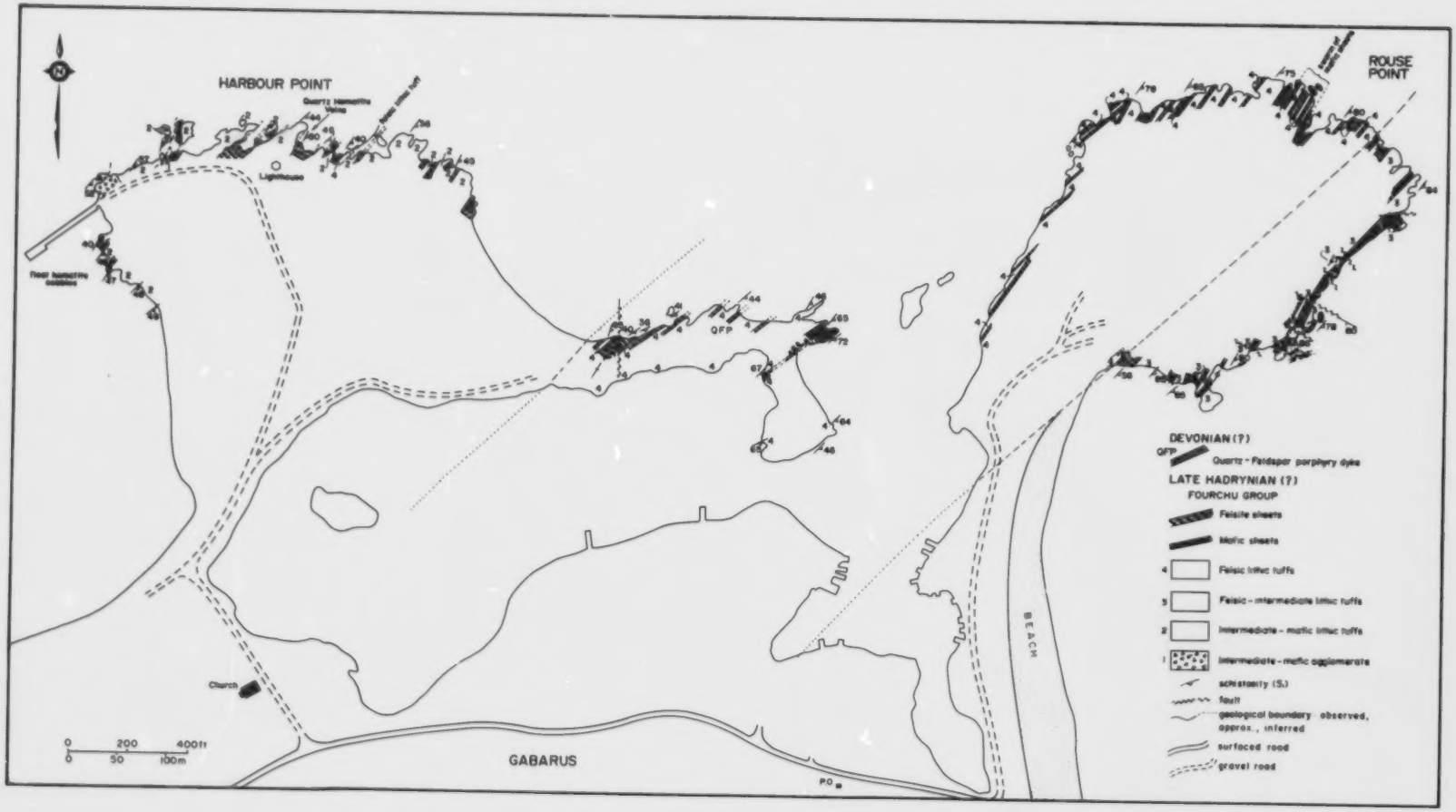


Figure 2-3. Detailed geological map showing the distribution of intrusive sheets and dykes in the vicinity of Gabarus Harbour.

brown biotite may occur in some laminae. Anhedral aggregates of epidote are common as are quartz-epidote-pyrite disseminations and veinlets (Fig. 2-2b).

Mafic sills are also widespread and are particularly abundant at Rouse Point where they constitute a swarm (Fig. 2-3). Being typically dark green in appearance they resemble the mafic flows, but are in general more pervasively foliated and are perhaps best described as greenstones or greenschists. They form sheets up to several metres thick generally conformable with bedding and foliation (S_{0-1}) in the country rocks, but they also branch locally and hence may be obliquely crosscutting.

In thin section, it can be seen that the original igneous fabric of these rocks has been largely destroyed. They consist of more or less foliated assemblages of plagioclase, chlorite, epidote, actinolite-tremolite, hematite or limonite or both, together with varietal biotite and quartz (Fig. 2-2h). The original plagioclase phenocrysts appear to have been replaced by sprays of prismatic actinolite-tremolite, whereas the more abundant plagioclase (An_{6-11}) laths look fresh and are presumably recrystallized.

Age relations between the felsic and mafic suites are commonly ambiguous where seen in contact because of their coplanarity and the obscuring of any chilled contacts by metamorphic recrystallization. However, at one locality east of Gabarus lighthouse, a 3 m thick mafic sill is clearly and extensively veined by felsite.

Foliated andesite porphyry forms two poorly exposed bodies occurring within felsic to intermediate tuffs north of Irish Brook (Fig. 2-1). These bodies are thought to be plugs, intrusive into the tuffs, although direct evidence of such a relationship is lacking. The rocks are yellowish-green to dark green in colour, massive, and commonly quartz veined. At several localities (Fig. 2-1), pyrite and rare pyrrhotite occur in patchy disseminations in fractures and in quartz veins within and adjacent to one of these bodies. In thin section, the porphyries consist of plagioclase phenocrysts (An_{33}) altered to sericite and epidote, and chloritic pseudomorphs after mafic phenocrysts in fine- to medium-grained matrices of plagioclase, chlorite, epidote and rarely actinolite. The opaques are oxidized to hematite and(or) goethite.

YOUNGER INTRUSIVE ROCKS

Three groups of younger intrusions cut the Fourchu Group: a gabbro body, basalt dykes and quartz-feldspar porphyry dykes. None of these are foliated, nor do they appear to have been metamorphosed although some are moderately altered. Age relationships among these three groups are unknown.

The gabbro is a crudely elliptical mass extending about 600 m southeastward from Irish Brook. It is a dark greenish, coarse grained rock composed of sericitized plagioclase, large poikilitic hornblende much altered to chlorite, skeletal opaques and accessory quartz.

Several basalt dykes, up to 2 m wide, outcrop on the southern and western shores of Gabarus Bay. They trend east-northeastward to southeastward, crosscutting the main structural trend of the Fourchu Group and paralleling important fault and joint directions. They are dark grey to grey-brown, fine- to medium-grained feldspar porphyritic basalts, generally rather altered and locally amygdaloidal. They consist of sericitized plagioclase phenocrysts in an intergranular groundmass of plagioclase laths, chlorite, calcite

and hematite with accessory quartz and apatite. From their petrographic similarities, the dykes may be related to the gabbro previously described.

A number of unfoliated feldspar and quartz-feldspar porphyry dykes, up to 3 m thick, intrude the Fourchu Group, trending north-northeastward to east-northeastward. These are grey-pink to brownish and porphyritic-aphanitic. Locally, they contain disseminated pyrite and appear moderately altered. In thin section, they consist of strongly zoned plagioclase phenocrysts, with or without quartz phenocrysts, and smaller biotites in very fine grained groundmasses of plagioclase, biotite, chlorite and quartz-K-feldspar intergrowths. They closely resemble minor intrusive phases associated with the Deep Cove Pluton and may therefore be of the same Devono-Carboniferous age.

GRANTMIRE FORMATION(?)

The only layered rocks, other than those of the Fourchu Group, which occur within the mapped area are several isolated occurrences of immature clastic rocks. These unconformably overlie and are in fault contact with rocks of the Fourchu Group (Fig. 2-1). They consist of very coarse sedimentary breccia and minor interbedded brown lithic sandstone. Clasts in the breccia are angular to subangular blocks of Fourchu volcanic and pyroclastic rocks up to 1 m across. Because their general similarity to the cobble conglomerate, grit and brown limestone which unconformably overlie the Fourchu Group at MacIntyre Lake, some 10 km to the southwest, these rocks are tentatively assigned to the Grantmire Formation. The distribution of these clastic rocks around the edge of the bay suggests that Gabarus Bay may represent an exhumed Carboniferous basin.

STRUCTURE

Given the predominance of coarse volcaniclastic rocks and of related volcanic and intrusive rocks in the area, primary layering and bedding are neither widely nor well developed and are generally obscured by intrusion of felsic and mafic sheets or by the development of subparallel tectonic foliation or both. Thus the primary control required to clearly define the location and geometry of any large-scale fold structures within the area is weak.

DUCTILE DEFORMATION

Minor Structures

The dominant minor structure observed in the Gabarus area is a penetrative schistosity (S_1). Its intensity in outcrop varies widely, but it can always be clearly observed in thin section. Where contacts within the various volcanic and pyroclastic units can be observed, the schistosity is usually subparallel to them, except in the vicinity of rare minor folds. This schistosity has a very uniform orientation (Fig. 2-4c) striking north-northeast to northeast and dipping at moderate to steep angles toward the east, except near Cape Gabarus where a local reversal of dip occurs. Most intrusive contacts and rare bedding have orientations very similar to the schistosity (Fig. 2-4a, b). Thus the felsic and mafic sheets are probably either pre- or syntectonic and any early folding is tight to isoclinal. Given the volcaniclastic nature of most of the rocks, lineations are poorly developed. However, in the lithic tuffs, fragments which are generally crude flattened ellipsoids within S_1 are locally also distinctly elongated in a steeply plunging south-southeast direction (Fig. 2-4d). This crude stretching lineation (L_1) parallels the axis of the only early minor fold recognized in the area.

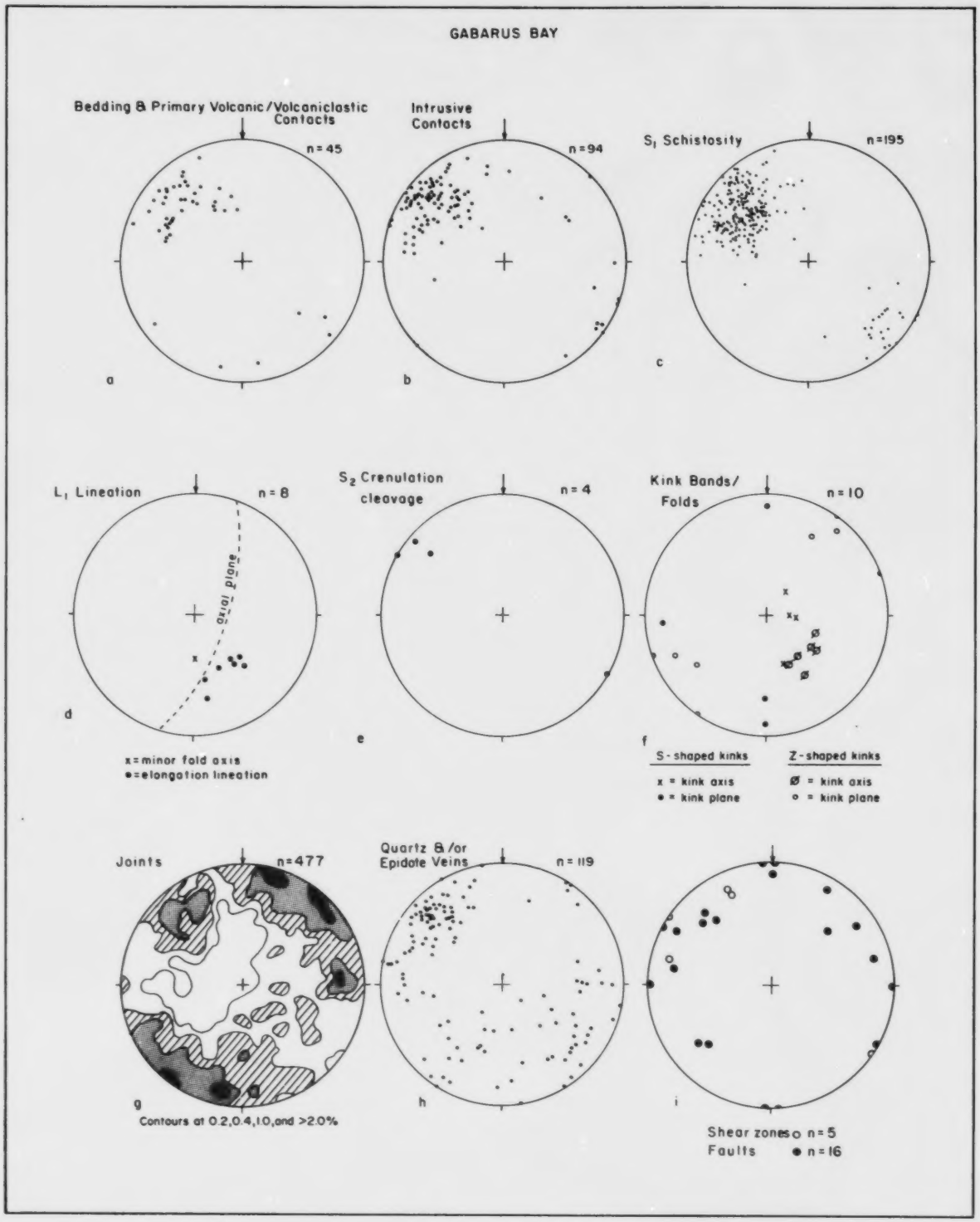


Figure 2-4. Summary of structural data from Gabarus Bay area.

A second foliation (S_2) can be detected locally in fine grained rocks both in outcrop and in thin section. This foliation is a weakly developed crenulation cleavage which, from the few measurements made, strikes northeast and dips subvertically (Fig. 2-4e). No minor folds were found directly associated with this second cleavage.

Ubiquitous, but sparsely developed, kink bands and minor kink folds with associated weak fracture cleavages (S_3) also occur within fine grained rocks. Insufficient numbers of these were available to clearly separate them into sets according to their orientations and asymmetries. However, the most common orientations (Fig. 2-4f) appear to be:

(1) east-trending, steeply plunging S-shaped kinks

(2) southeast-trending, moderately plunging Z-shaped kinks

Comparison with Louisbourg Area

The structural history of the Fourchu Group in the Gabarus area broadly resembles that in the Louisbourg area defined by Murphy (1977) (Table 2-1). However, in the latter area, where bedding is better developed in laminated ash units, F_1 minor folding is more common and has been described as open, upright folding (mainly Class 1B) plunging at low angles to the east-northeast. In addition, no kink bands and related minor folds (F_3) have been described at Louisbourg.

Major Structure

No major structure, such as the anticline shown by Weeks (1954), could be confirmed within the Gabarus area even though the general coplanarity of bedding and schistosity, and the steeply plunging L_1 elongation lineations and rare minor F_1 folds suggest that tight to isoclinal folding has occurred. Only in a few places could bedding be clearly distinguished from the S_1 schistosity. Near Rams Head, in the central part of the area, bedding dips more steeply southeastward than foliation, indicating that structural overturning has occurred. Elsewhere to the northwest and southeast, sparse evidence shows that beds are facing upward. This is compatible with large-scale asymmetric folding (F_1) verging toward the northwest, however there are insufficient data to precisely define the number and positions of major fold closures (no hinge areas were detected in the course of mapping). One possible structural interpretation is shown on the cross-section on Figure 2-1. According to this interpretation, the structure is dominated by a large synform occupied by volcaniclastic rocks, flanked by antiforms cored by volcanic and volcaniclastic rocks.

Near Cape Gabarus there is a general reversal in the directions of dip of both S_0 and S_1 planar structures (Fig. 2-1). This is probably due either to major upright synformal folding (F_2?) or simply to broad warping (F_3?). While the orientation of the S_2 crenulation cleavage tends to support the former hypothesis, the relative lack of late minor structures precludes confident identification of this structure.

BRITTLE DEFORMATION

Joint patterns around Gabarus Bay are relatively systematic: plots from individual subareas correlate closely with the synoptic plot for the whole area (Fig. 2-4g). The latter plot indicates the existence of four main joint sets:

(1) north-south strike, steep dips to the west;

(2) northeast-southwest strike,

Table 2-1. Comparison of minor structures recognized in Gabarus and Louisbourg areas.

Event	Element	Gabarus area (this study)	Louisbourg area (Murphy, 1977)
D_1	S_1	penetrative schistosity, striking NE to NNE and dipping steeply east	penetrative cleavage/schistosity striking ENE, and dipping steeply NNW or SSE
	F_1	rare tight folds plunging steeply	open to close folds plunging gently ENE
	L_1	elongation of lithic clasts, plunging steeply to moderately SSE	S_0/S_1 intersections plunging gently ENE
D_2	S_2	sporadic weak crenulation cleavage, striking NE, and dipping steeply SE	nonpenetrative slip/crenulation cleavages striking NE, dipping steeply SE
	F_2	no minor folds recognized	no minor folds recognized
	L_2	no lineations recognized	S_1/S_2 intersections plunging gently ENE
D_3	S_3	weak fracture cleavage(s)	
	F_3	more than one set of kink bands and related kink folds plunging steeply to moderately E and SE	not described

steep dips to the southeast;

(3) west-northwest to east-southeast strike, subvertical dips; and

(4) northwest-southeast strike, subvertical dips.

While the age relationships are unknown, sets (2) and (4) are subparallel and subperpendicular respectively to the dominant structural trend and therefore probably represent longitudinal and cross joints formed during the release of regional stresses. Sets (1) and (3) are possibly related to younger faulting.

Faults in the area were observed mainly in the well-exposed coastal sections. Three main sets were distinguished (Fig. 2-4i):

(1) north to northeast striking, steep dips to the east;

(2) west-east striking, subvertical dips; and

(3) northwest-southeast striking, steep dips to the northeast or southwest.

The movement on at least some of the north to northeast striking faults post-dates deposition of the coarse clastic rocks (Grantmire Formation?) which unconformably overlie the Fourchu Group. The east- and southeast-trending sets of faults are parallel to a suite of mafic dykes. However, the relative ages of these sets of faults are not known.

Veins of quartz, with or without epidote, hematite and minor sulphides, are common throughout the area, particularly in the more massive competent units (felsite sheets, welded tuffs, etc.). They range from isolated regular veins, through swarms, to irregular stockwork and gash systems. Orientations of more regular veins (Fig. 2-4h) closely parallel the common joint patterns: principally northeast-southwest, northwest-southeast, and north-south.

A few shear zones (Fig. 2-4i) were noted which generally subparallel the regional northeast trend. From their retrograde features they are thought to post-date regional metamorphism and associated deformation and possibly to pre-date faulting.

METAMORPHISM

The rocks of the Fourchu Group are clearly metamorphic, but are of low metamorphic grade as indicated by the metamorphic mineralogy, the fine grain sizes of metamorphic minerals and the survival of detailed primary structures.

Metamorphic minerals most commonly include sericite, epidote, chlorite and pyrite, but minor amounts of very fine grained biotite, tremolite-actinolite and plagioclase occur locally. The phyllosilicates possess a very strong preferred orientation which creates the penetrative S_1 cleavage/schistosity. Epidote occurs as fine granular material disseminated throughout rocks, or within layers of appropriate composition, or as concentrations pseudomorphing mafic phenocrysts and partially replacing plagioclase phenocrysts in volcanic rocks and rock fragments. Very fine grained stubby biotite and sprays of tremolite-actinolite are apparently restricted to the more schistose mafic rocks. Pyrite appears to be the only true porphyroblastic mineral, locally forming abundant cubic porphyroblasts up to 2 cm across in chloritic schists and intermediate to mafic meta-tuffs. The common association of pressure shadows indicates that some deformation, perhaps late D_1 or D_2, followed their crystallization.

As the phyllosilicates parallel the S_1 schistosity and have been rotated and bent during the development of the S_2 crenulation cleavage, it can be deduced that regional metamorphism accompanied the D_1 deformation, but had waned prior to the D_2 and D_3 deformations.

From the mineralogies of the various rock types, the facies of regional metamorphism can be deduced as lower greenschist facies, transitional between quartz-albite-muscovite-chlorite and quartz-albite-epidote-biotite subfacies (Winkler, 1967). No garnet porphyroblasts were observed, such as those reported from the Fourchu Group in the Louisbourg area (Murphy, 1977) which, although retrograded, indicated the peak of regional metamorphism attained quartz-albite-epidote-almandine subfacies. Hence it may be that there is a slight decrease in metamorphic grade across the Fourchu Group from east to west.

This regional metamorphic event occurred under medium pressure and low to medium temperature Barrovian conditions.

PETROCHEMISTRY OF VOLCANIC AND RELATED INTRUSIVE ROCKS

Samples from nine flows, one mafic sill, two felsic sills and the Gull Cove crystal tuff were analyzed for major oxides and for eighteen minor and trace elements (Table 2-2). Although all of these rocks have experienced low grade metamorphism and penetrative deformation, the volatile contents are relatively low with H_2O ranging from 0.5 - 3.2% and CO_2 less than 0.1%. The Fe_2O_3/FeO ratios range from 0.2-2.8%,

Table 2-2. Geochemical analyses of volcanic and related intrusive rocks of the Fourchu belt.

MAJOR OXIDES (%)	BASALT SHEET	BASALT AND ANDESITE FLOWS						DACITE FLOWS			FELSITE SHEETS (DACITE)		QUARTZ-FELDSPAR CRYSTAL TUFF (RHYODACITE)	
SAMPLE NUMBER	F16-8555	F16-8171	F16-8105	F16-8079	F16-8078	F16-8077	F16-9054	F16-9121	F16-9025	F16-8101	F16-9070	F16-9005	F16-9076	F16-9058
Silica	46.85	48.59	52.66	53.05	54.73	54.84	56.07	60.72	63.15	67.67	69.03	69.85	71.73	74.47
TiO_2	1.75	1.02	1.29	1.67	1.54	1.19	1.00	0.67	0.85	0.62	0.72	0.80	0.27	0.17
Al_2O_3	15.87	17.92	19.98	15.76	15.06	16.61	15.27	18.19	16.07	14.16	14.60	13.36	14.03	11.74
Fe_2O_3	5.12	1.54	3.46	4.29	5.94	3.05	5.49	4.24	2.25	2.77	1.01	1.32	1.35	1.44
FeO	7.10	7.09	3.93	7.20	5.61	6.95	5.74	2.71	3.13	1.00	2.37	2.07	0.80	0.68
MnO	0.27	0.26	0.15	0.23	0.28	0.20	0.25	0.07	0.17	0.10	0.12	0.11	0.04	0.04
MgO	4.89	7.53	2.81	4.18	3.81	3.50	3.70	1.79	1.69	1.13	0.92	1.08	0.60	0.31
CaO	9.43	9.35	7.00	8.65	6.60	5.16	7.41	2.37	3.05	5.83	2.18	3.05	1.87	3.35
K_2O	0.30	1.15	0.40	0.62	0.73	0.67	0.66	1.47	0.96	1.61	1.51	0.43	2.60	1.15
Na_2O	2.93	2.55	4.81	3.11	4.87	4.18	3.14	3.54	5.80	2.64	5.20	5.15	4.33	4.33
H_2O^+	3.01	1.19	2.32	1.26	1.06	3.09	1.42	2.11	1.43	0.81	1.24	1.08	0.69	0.53
H_2O^-	0.14	0.08	0.00	0.07	0.06	0.06	0.00	0.01	0.04	0.06	0.00	0.00	0.02	0.00
P_2O_5	0.53	0.19	0.26	0.53	0.52	0.44	0.25	0.20	0.25	0.18	0.14	0.18	0.09	0.09
CO_2	0.20	0.05	0.07	0.04	0.07	0.05	0.02	0.05	0.02	0.05	0.02	0.05	0.04	0.02
TOTAL OXIDES	98.39	98.52	99.14	100.70	100.88	99.99	100.42	98.14	98.86	98.63	99.06	98.53	98.46	98.32
TOTAL IRON AS Fe_2O_3	13.01	9.42	7.83	12.94	12.17	10.77	11.87	7.25	5.73	3.88	3.64	3.62	2.24	2.20
TRACE ELEMENTS (ppm)														
Be	190	400	155	205	450	260	395	498	395	340	538	187	638	395
Rb	7	59	2	32	22	7	8	39	13	54	26	4	73	20
Sr	435	350	495	472	560	330	320	270	220	740	200	308	180	280
Zr	86	70	145	90	75	90	86	105	100	155	260	190	225	200
F	460	280	600	430	430	450	340	690	290	240	340	290	250	220
Li	16	21	9	9	9	20	13	39	18	13	8	6	13	4
Y	25	16	30	28	20	35	18	22	27	38	39	30	14	10
Sn	1	1	3	7	6	5	2	2	2	4	3	3	2	1
Cu	41	62	39	14	12	17	160	10	4	5	-1	1	-1	1
Mo	3	4	7	4	3	3	3	3	3	4	3	4	3	3
Pb	8	4	10	12	10	8	22	2	8	76	6	8	8	15
Zn	150	87	77	98	109	180	155	104	103	143	101	64	44	22
Ag	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bi	0.3	0.1	0.3	1.1	1.1	1.4	0.2	0.1	0.1	0.3	0.1	0.1	0.1	0.2
S	80	160	680	100	120	280	1360	60	80	120	60	60	40	60
Co	25	38	10	19	18	13	27	15	4	1	1	1	1	-1
Ni	195	133	100	22	45	12	22	50	7	1	1	4	3	2
Cr	380	450	390	22	36	24	38	175	35	30	22	20	20	34

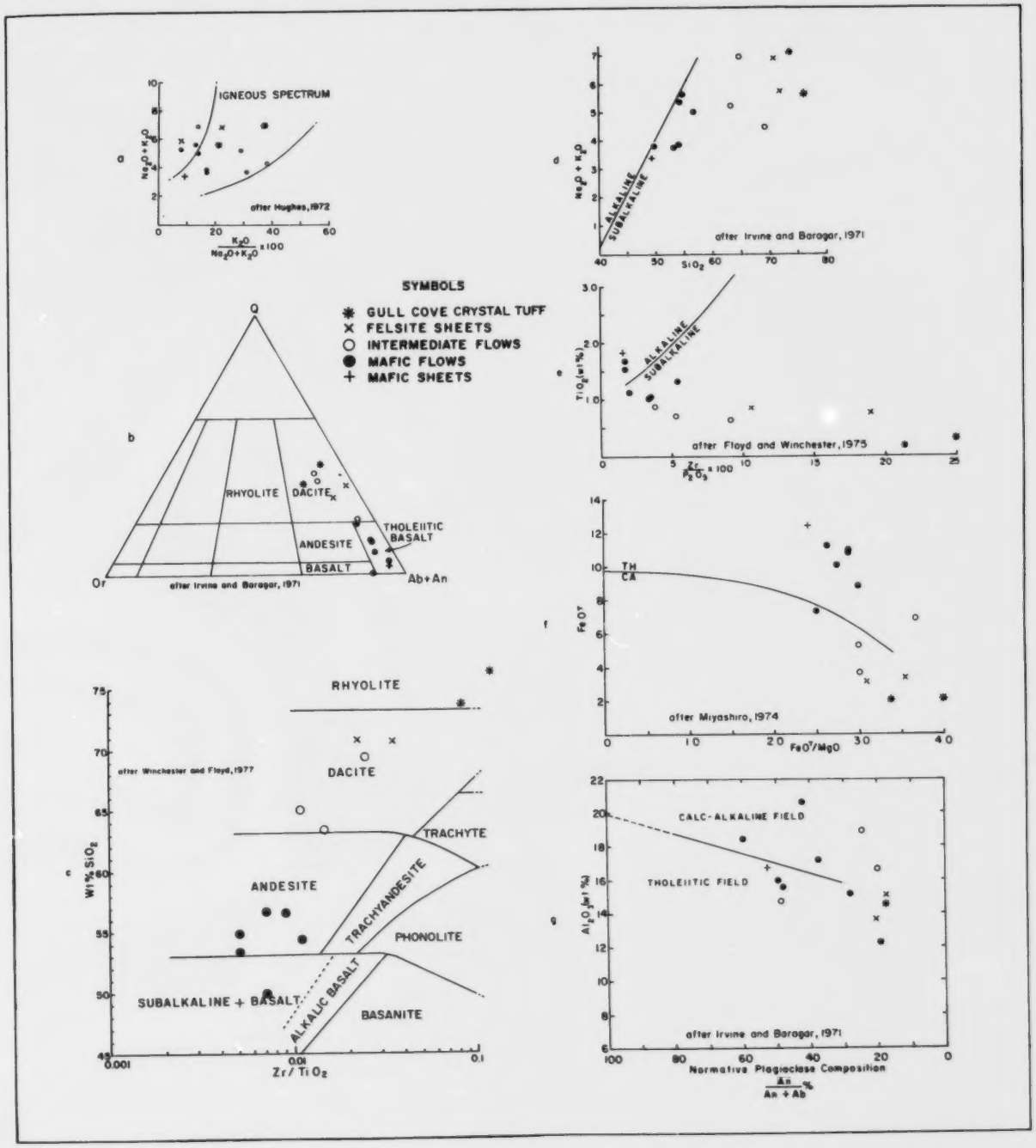


Figure 2-5. Geochemical discrimination diagrams for Fourchu Group volcanic and related intrusive rocks.

with the majority being less than 1%. Plotted on Hughes' (1972) igneous spectrum (Fig. 2-5a), two thirds of the samples fall within the normal igneous spectrum for Na_2O and K_2O values, but the other one third fall within the spilitic spectrum (i.e. enriched in Na_2O), suggesting that caution be exercised in using the more mobile elements for classification.

Based on SiO_2 contents (volatile-free), normative quartz-K-feldspar-plagioclase proportions (Fig. 2-5b) and a plot of SiO_2 vs. Zr/TiO_2 (Fig. 2-5c), the volcanic rocks range from basalt through andesite to dacite, whereas the mafic sill is basaltic and the felsic sill and quartz-feldspar crystal tuff are dacitic to rhyodacitic.

Plotted on $Na_2O + K_2O$ vs. SiO_2 and TiO_2:Zr/P_2O_5 diagrams, the samples are seen to be essentially subalkaline on both diagrams (Figs. 2-5d, e). The same pattern is incidentally shown by the plot of SiO_2:Zr/TiO_2 (Fig. 2-5c).

Based on the major oxide chemistry and specific subalkaline character, these rocks appear to be transitional from tholeiitic into calc-alkaline as shown by plots of total FeO: total FeO/MgO (Fig. 2-5f) and Al_2O_3: normative plagioclase (Fig. 2-5g). However, plots involving total FeO and MgO may not be very reliable for characterizing metavolcanic rocks (Garcia, 1978). The tectonic setting of the more mafic members can be deduced using discrimination diagrams involving less mobile major oxides such as MgO-total FeO-Al_2O_3 (Pearce et al., 1977), and relatively immobile minor trace elements such as Zr-Ti-Y (Pearce and Cann, 1973). In the former diagram (Fig. 2-6a) the samples are scattered, but tend to straddle the boundary between the orogenic and continental fields. However, in the latter (Fig. 2-6b) they fall mainly within the overlapping fields of calc-alkaline basalts, low-K tholeiites and ocean-floor basalts.

Considering all the evidence from both the major oxide data and from the minor and trace element data (especially those involving the less mobile elements), the suite of volcanic and associated intrusive rocks from Gabarus Bay appears to be mainly a comagmatic suite, transitional between low-K tholeiites and calc-alkaline magmatic types, presumably generated in an orogenic, ensialic magmatic arc. The transitional nature of this suite could indicate a locus of generation on the side of the arc proximal to the paleotrench, or on relatively thin continental crust or both. Such a conclusion is consistent with that of Keppie et al. (1979) for the Fourchu Group in the Louisbourg area.

MINERALIZATION

To date, the most important mineralization found in the vicinity of Gabarus Bay is the polymetallic sulphide mineralization at Deep Cove with its satellite occurrences at Eagle Head and on Kennington Cove Brook. This mineralization appears to be hydrothermal epigenetic in type, genetically and spatially associated with an altered granitic stock which has intruded and hornfelsed rocks of the Fourchu Group (Bingley, 1969; Riddell, 1973; Sangster, 1977b).

Other showings and occurrences of base metal mineralization have been reported from the general area (Fig. 0-1). These are perhaps best described as Fe-Cu occurrences consisting mainly of Fe sulphides, and(or) oxides and hydroxides with associated minor to trace amounts of Cu minerals. Of these occurrences, only those in the vicinity of Irish Brook and MacIntyre Lake have been investigated in any detail: the former by soil and stream sediment geochemistry and limited diamond-drilling

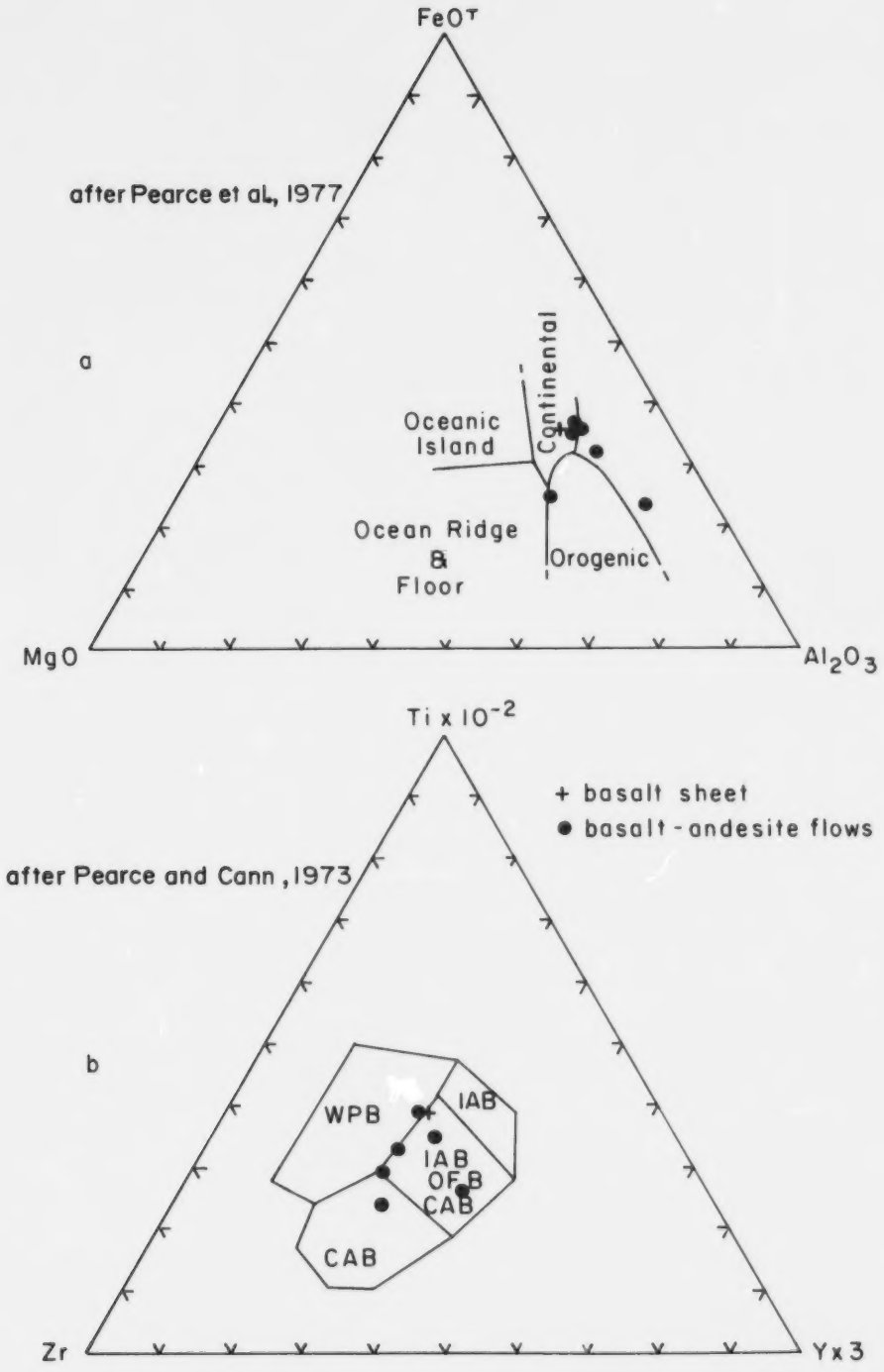


Figure 2-6. Tectonic setting diagrams for Fourchu Group mafic volcanic and related intrusive rocks.

(Leslie, 1969) and the latter by pitting, trenching and diamond-drilling (Perusse, 1960).

In addition to the above reported occurrences, several other occurrences or showings in roadside outcrops along the Gabarus-Marion Bridge road, near Gull Cove, were observed and sampled during mapping.

DEEP COVE

For comparison with other occurrences of mineralization in the area of Gabarus Bay, the Deep Cove property (Fig. 2-7) was briefly examined and 1840 m of core were logged. The core had been drilled in 1976 by St. Joseph Explorations Limited and in 1979 by Louisbourg Mines Limited. A total of 30 thin sections were also studied to help establish some of the more obvious effects of alteration on both the host granite and the older volcanic rocks of the Fourchu Group, and its relationship to mineralization.

The granitic intrusion is a small, roughly elliptical stock with a faulted western margin and a more shallowly dipping eastern margin (Fig. 2-7). The western margin is in part sheeted, and granitic sheets also intrude the Fourchu Group at several localities along the shore. Petrologic studies (O'Beirne, 1979; Barr et al., 1982) have shown these intrusive rocks to be variably porphyritic granites of calc-alkalic affinity. The Rb/Sr age of the stock is 342 ± 20 Ma (Cormier, 1972; Keppie and Smith, 1978), but a K/Ar mica age of 387 Ma (M. Zentilli, personal communication, 1983) suggests perhaps that the Rb/Sr age has been disturbed by pervasive alteration.

The mineralization has been described as being of two main types (Riddell, 1973; Forgeron, 1974):

(1) simple molybdenite mineralization, as veins and disseminations, best developed along the faulted western contact of the stock; and

(2) polymetallic (Cu, Zn, Mo, Bi and Ag) mineralization in several zones within the east-central part of the stock. Pyrite, chalcopyrite, sphalerite, molybdenite and bismuthinite are the sulphides present. The mode of occurrence of Ag has not yet been described, but a strong correlation with Zn values has been reported (Riddell, 1973).

The stock is extensively altered and there has been considerable speculation as to the types of alteration present, their distribution in space, zoning patterns (if any), and their relationship and significance with respect to mineralization (cf. Riddell, 1973; Chatterjee, 1976; Sangster, 1977b).

Logging of available core (see representative logs on Fig. 2-7) shows that alteration is pervasive and extends to depths of at least 150-250 m beneath the surface before fading into very weakly altered or essentially unaltered grey granite (Fig. 2-8a). Superimposed on this pervasive alteration are numerous zones of more localized, intense, essentially reconstructive alteration, which are apparently most extensively developed within 60-90 m of the present surface. Much of this intense alteration appears to be closely associated with fracturing and veining, although some diffuse zones were also observed.

Pervasive Alteration

The pervasively altered granite ranges from pale pink to pink and dull green. In the slightly altered pale pink granite, the plagioclase phenocrysts are sericitized, and anhedral biotites (3-10%) are partially altered to chlorite with or without minor

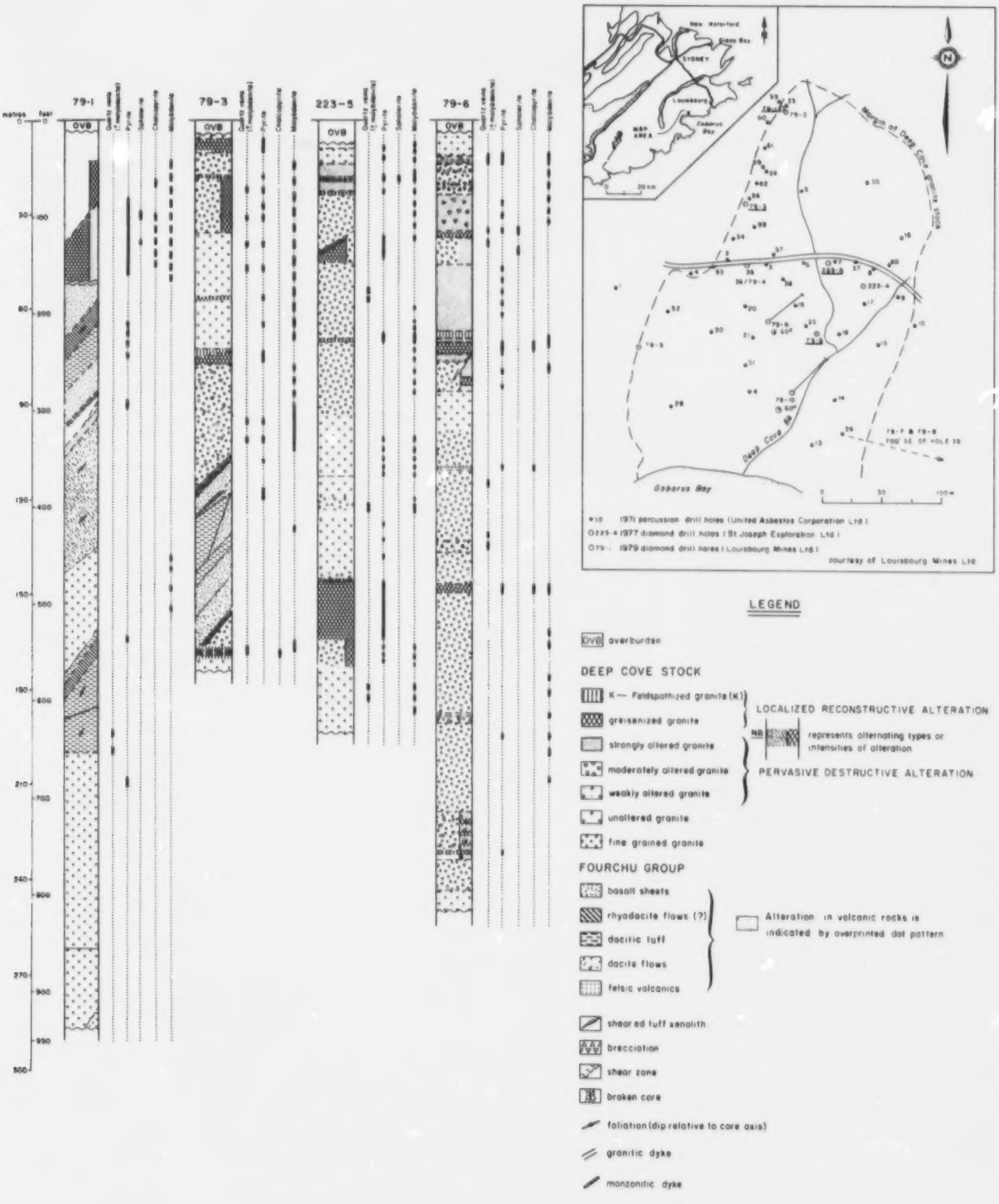


Figure 2-7. Drillhole location map and representative drill core sections, Deep Cove Brook, Gabarus Bay.

sericite. With increasing alteration, the plagioclase becomes dull green due to extensive alteration to saussurite and hydromicas(?), whereas the biotite becomes dull bronze due to extensive alteration to sericite and chlorite (Figs. 2-8b, c).

Localized Alteration

Two distinctive types of localized reconstructive alteration are recognized, namely greisenization and K-feldspathization.

Greisenization has produced common, generally narrow zones (2-3 cm to 20 m thick) of quartz-sericite-pyrite greisen. Typically, this is a yellowish-grey to grey, subporphyritic to aplitic rock consisting of subporphyritic quartz, commonly with sutured grain boundaries, in a fine- to medium-grained allotriomorphic inequigranular groundmass of quartz, sericite, orthoclase, calcite and pyrite (Fig. 2-8d) within which may still be recognized some ghostly outlines of plagioclase and biotite, completely pseudomorphed (respectively) by saussurite, hydromicas(?), sericite and calcite, and by sericite, chlorite, calcite, rutile(?) and leucoxene(?). Such greisens are locally cut by veinlets of calcite and(or) quartz with varying amounts of fine grained pyrite. Some of these greisen zones have subsequently been sheared or brecciated and these display highly strained quartz and kinked sericite. The greisens may either grade through

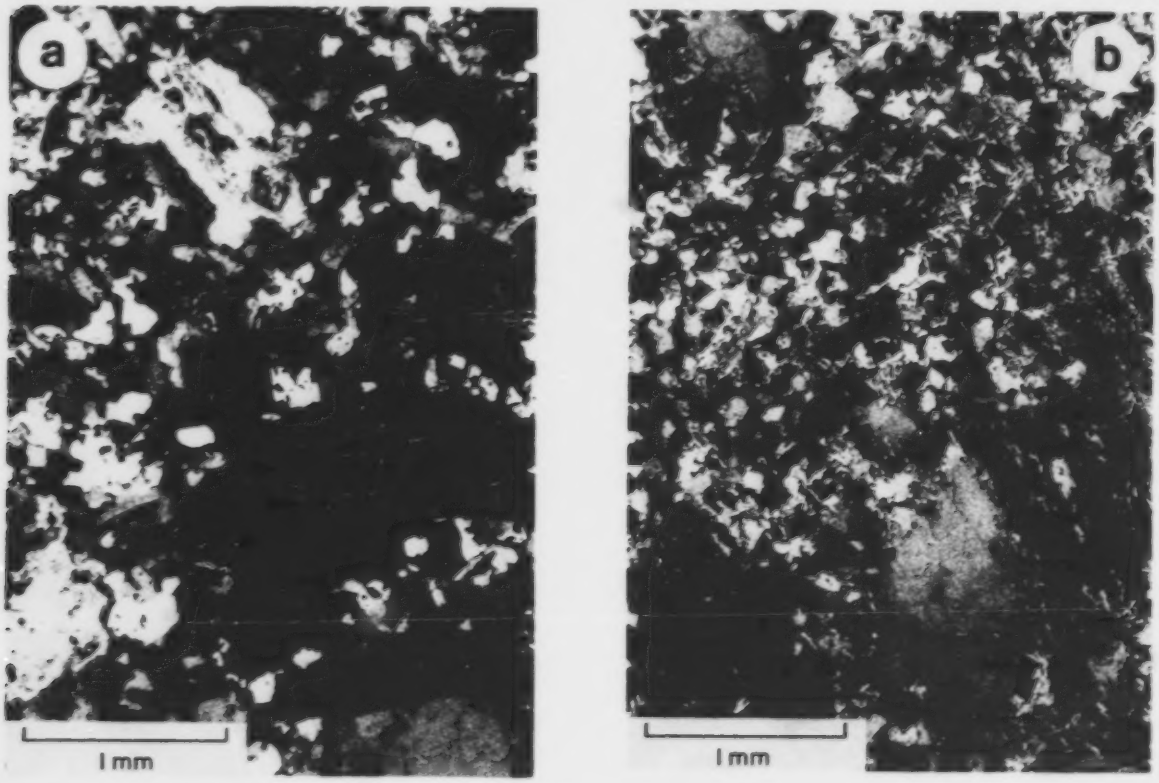
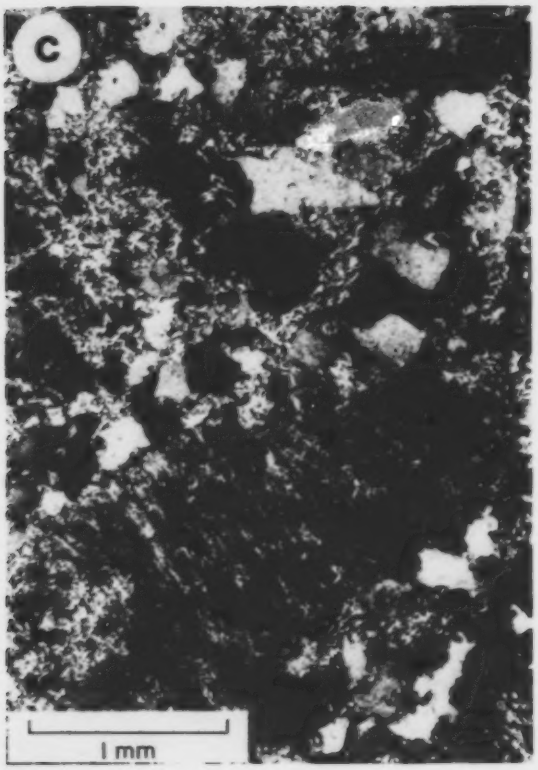


Figure 2-8. Alteration of Deep Cove granite.
a. Relatively fresh biotite granite.
b, c. Highly altered granite with chloritized and sericitized biotite phenocrysts (c over).
d. Greisenized granite with relict quartz phenocryst (over).



greisenized granite into altered granite or they may be flanked by relatively distinct K-feldspathized zones.

Narrow zones of K-feldspathization up to 30 cm thick usually flank fractures, veins and greisen zones; less commonly they form diffuse zones up to 1 m wide lacking any obvious focus, and rarely they flank narrow biotite-rich zones. In appearance, these zones are intensely pink and range in texture from normal porphyritic to more equigranular aplitic. Typically these rocks consist of quartz, microcline, plagioclase and fresh biotite (hydrothermal?) with hypidiomorphic to allotriomorphic granular textures.

The relationships between these two types of alteration are somewhat ambiguous in the sense that greisen zones are locally, but not ubiquitously, flanked by K-feldspathized zones but the latter commonly occur in the absence of greisen zones (Fig. 2-7). Where measurable, orientations of these zones are variable relative to the drill core axes, but most generally fall in the range 30-55°, indicating that they are moderately to steeply dipping. Their strikes could not be directly determined from the core but Riddell (1973) has shown that the granite has been cut by two principal directions of veins, fractures and shears: (1) striking 030-050° and dipping 30-50° northwest (veins and fractures) and (2) striking 090-110° and dipping 60-70° south (shears and fractures).

Association with Mineralization

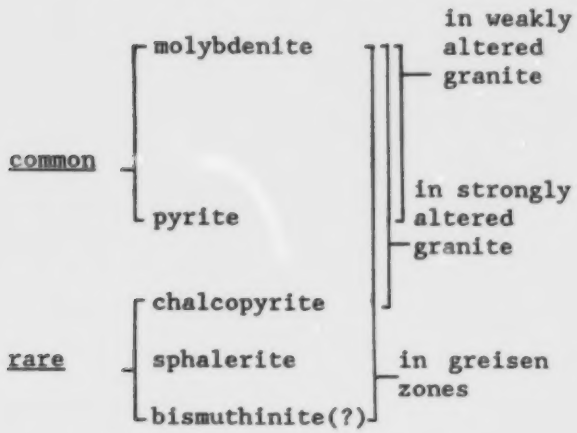
Mineralization observed in the core has several modes of occurrence:

(1) a quartz veins (<5 cm) with coarse molybdenite ± pyrite cutting all rock types

b calcite ± quartz veinlets (<1 cm) with fine pyrite ± molybdenite cutting greisen zones

(2) dry fracture coatings of pyrite ± molybdenite

(3) sparse disseminations:



In general, these sulphides are widely, if sparsely, distributed throughout the core. However, some broad patterns of distribution can be discerned in the core:

(1) more common occurrences of molybdenite in quartz veins and in disseminations in altered granite above the footwall volcanic rocks along the western margin of the stock (Drillholes 79-1 and 3 in Fig. 2-7). Two holes, DC-2 and DC-25, percussion drilled in 1971, averaged 0.22% and 0.32% MoS_2 over 26 m and 40 m respectively (Forgeron, 1974).

(2) sphalerite and(or) chalcopyrite with traces of bismuthinite(?) usually associated with molybdenite and more abundant pyrite appear to occur more commonly in the central and eastern parts of the stock - a pattern that was described by Riddell (1973) and Forgeron (1974) on the basis of geochemistry derived from the 1971 percussion-drilling program. Whereas the sphalerite (and bismuthinite?) appears to be restricted to greisenized and intensely altered zones occurring within about 75 m of the surface, chalcopyrite is apparently more widely distributed and is found disseminated within both greisenized and pervasively altered granite reaching greater depths.

Alteration and Mineralization in Fourchu Group Rocks

In general, alteration and mineralization are much less obvious in drill core from the Fourchu Group rocks occurring along the western contact of the Deep Cove stock and farther away from the stock to the north and east. The rocks are primarily metamorphosed dacites, dacitic tuffs (some waterlain) and lesser rhyolites cut by metabasalt and rarer feldspar porphyry sills and by altered granitic sheets.

Pervasive alteration is apparently absent, with only localized alteration occurring over distances of a few cm, rarely up to 30 cm, adjacent to quartz veins, fractures, occasional breccia zones and a few intensely altered, usually K-feldspathized(?) granitic sheets. The most common type of alteration appears as a flesh-coloured bleaching of the Fourchu rocks, although in some places this is preceded by a narrower zone of pink K-feldspathization associated with such alteration, but also extending beyond it, are common quartz-calcite ± pyrite ± hematite veinlets, lesser molybdenite and pyrite fracture coatings and patchy disseminations of pyrite.

IRISH BROOK OCCURRENCES

Minor sulphide showings occur on Irish Brook and in roadside outcrops both to the north and south of the brook (Fig. 2-9). These occurrences are hosted by

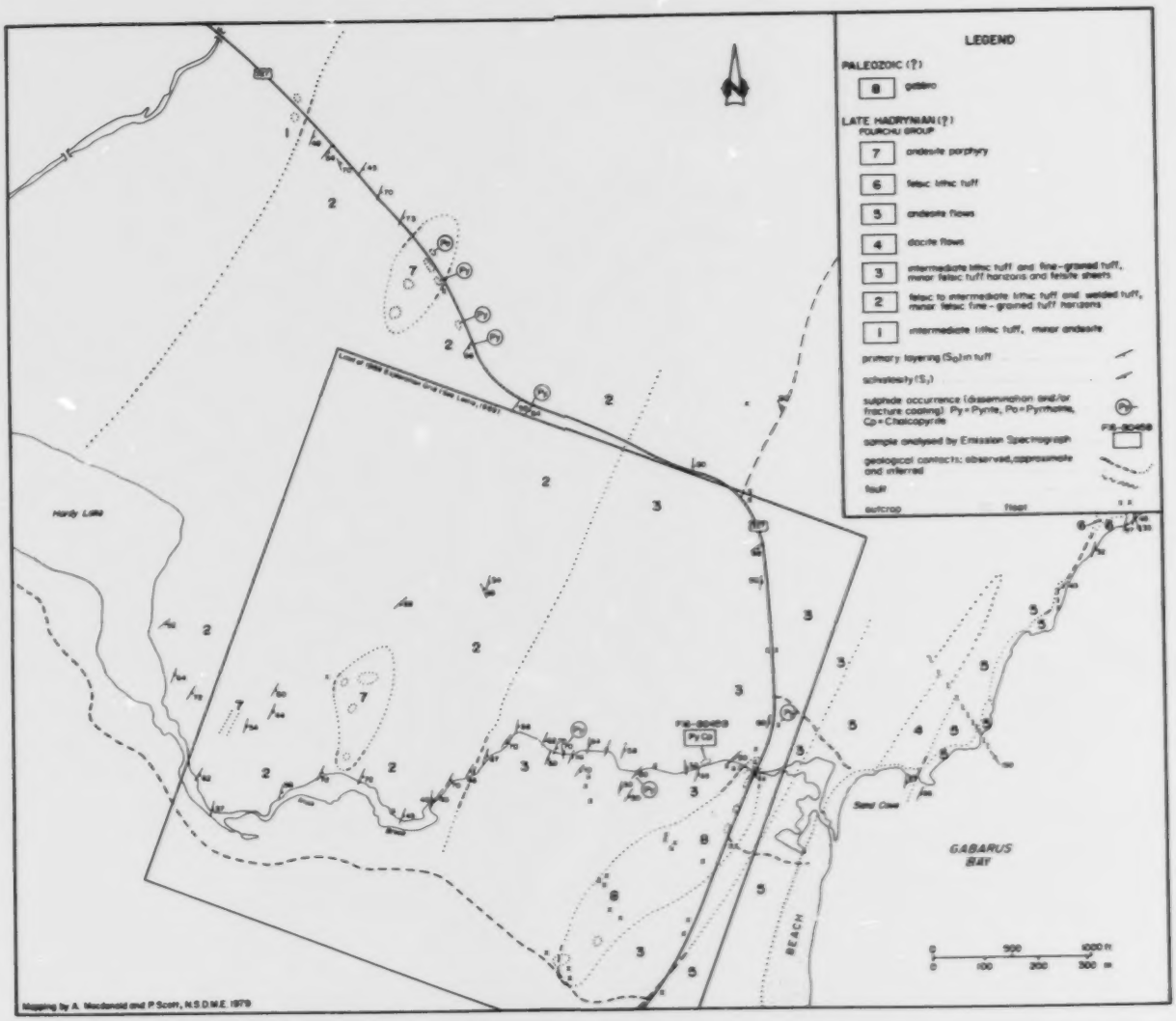

LEGEND
PALEOZOIC (?)
8 gabbro
LATE HADRYNIAN (?)
FOURCHU GROUP
7 andesite porphyry
6 felsic lithic tuff
5 andesite flows
4 dacite flows
3 intermediate lithic tuff and fine-grained tuff, minor felsic tuff horizons and felsite sheets
2 felsic to intermediate lithic tuff and welded tuff, minor felsic fine-grained tuff horizons
1 intermediate lithic tuff, minor andesite
primary layering (S0) in tuff
schistosity (S1)
sulphide occurrence (disseminations and/or fracture coatings) Py = Pyrite, Po = Pyrrhotite, Cp = Chalcopyrite
sample analysed by Emission Spectrograph
geological contacts: observed, approximate and inferred
fault
outcrop
float
Hardy Lake
GABARUS BAY
BEACH
Mapping by A. Macdonald and P. Scott, N.S.D.M.E. 1979

Figure 2-9. Detailed geological map of Irish Brook pyrite-chalcopyrite showings, Gabarus Bay, Fourchu belt.

a variety of metavolcanic and pyroclastic rocks of the Fourchu Group.

The main occurrence has been described as "a weakly mineralized copper zone about 20 feet wide in Irish Brook about 400 feet upstream from the highway", to the northeast of which a sizeable, but weak Cu anomaly with a peak value of 250 ppm has been defined by soil geochemistry (Leslie, 1969). An exploratory diamond-drill hole into this anomaly encountered tuffaceous andesite and andesite containing scattered sections of pyrite and pyrrhotite (2-3%) as fine disseminations and in veinlets. Scattered grains of chalcopyrite are associated with the veinlets within the more tuffaceous units. Copper values did not exceed 0.2% (Leslie, 1969).

For this study, pyritic showings at Irish Brook and in roadside outcrops to the north and south were sampled for ore microscopic and spectrographic studies.

The sulphides occur mainly as fine- to medium-grained sparse disseminations crudely conformable with layering and schistosity (S_{0-1}), as localized small aggregates and irregular masses, and as short (quartz-calcite) veinlets within intermediate to mafic lithic tuffs and andesites. Mineralogically the sulphides consist predominantly of pyrite with lesser magnetite, minor chalcopyrite, rare sphalerite and trace pyrrhotite.

Pyrite generally forms fine- to medium-grained subhedral to euhedral disseminated crystals, less than 2 mm in diameter, sufficiently concentrated locally to form irregular crystalline aggregates (Fig. 2-10a). Rarely, the crystals display skeletal habits. Magnetite occurs in fine grained anhedral to subhedral disseminations, rarely in aggregates or masses. Irregular to lamellar patches of hematite may occur within some magnetite grains. Chalcopyrite is generally found as small anhedral grains or patches occurring in localized sparse disseminations and in short veinlets, usually associated with pyrite. It also occasionally occurs as very small anhedral inclusions within pyrite, as narrow rims around pyrite, and as exsolved (?) emulsion blebs within rare sphalerite. Sphalerite occurs only rarely, as small anhedral patches adjacent to chalcopyrite (Fig. 2-10a). Pyrrhotite is found only as rare inclusions within some pyrite crystals.

Although the mineralization appears broadly conformable with layering and schistosity in the host rocks, the apparent lack of deformation and recrystallization features, together with its common occurrence in veinlets, suggest that it was introduced after deformation and metamorphism and is epigenetic. Source and conditions of deposition are as yet unknown.

Many of the samples show some alteration effects, presumably due to supergene weathering since they were collected from surface outcrops. Pyrite is commonly partially altered to goethite/limonite, and chalcopyrite displays thin rims of covellite.

A spectrographic scan of a single sample from the Irish Brook occurrence indicated a Cu concentration in the range 0.01-0.033% whereas a sample from a weakly mineralized roadside outcrop 0.5 km south of the brook contained 0.5-1.0% Cu (Table 2-3).

OCCURRENCES SOUTH OF GABARUS BAY

Minor pyritic occurrences are found along the southern shore of Gabarus Bay at Gull Cove (Figs. 2-2, 2-11) and Cape Gabarus (Fig. 2-1), and also farther to the south, outside of the mapped area, at Winging Point and on the Fourchu Road (Fig. 0-1). These occurrences show many similarities to those at

Irish Brook, except that chalcopyrite is either much rarer or absent. Typically, the occurrences are very fine- to medium-grained sparse disseminations ranging from dispersed to local irregular aggregates locally concordant with the S_0-$_1$ layering and foliation. Short veinlets may also be present, and in one example from Gull Cove, the mineralization occurs entirely within quartz veins. In these occurrences, the mineralization covers no more than a few square metres and the concentration is generally less than 2-3% sulphides by volume, except at the Cape Gabarus occurrence where mineralized boulders from the till bank on the east side of Gull Cove contain 10-15% pyrite.

The mineralogy consists predominantly of pyrite, with lesser magnetite and associated hematite, minor chalcopyrite and very rare bornite and pyrrhotite. Pyrite forms subhedral to euhedral cubes, octahedra and aggregates (Figs. 2-10b to d), except in some material from Gull Cove which is anhedral and inclusion-filled. Magnetite forms fine grained anhedral disseminations and rare coarser aggregates in which lamellar intergrowths of hematite can be seen (Fig. 2-10b). Chalcopyrite is quite uncommon and is found only as isolated small anhedra at or near pyrite grain boundaries, some possibly in weak pressure shadows, or as small inclusions within pyrite (Fig. 2-10c).

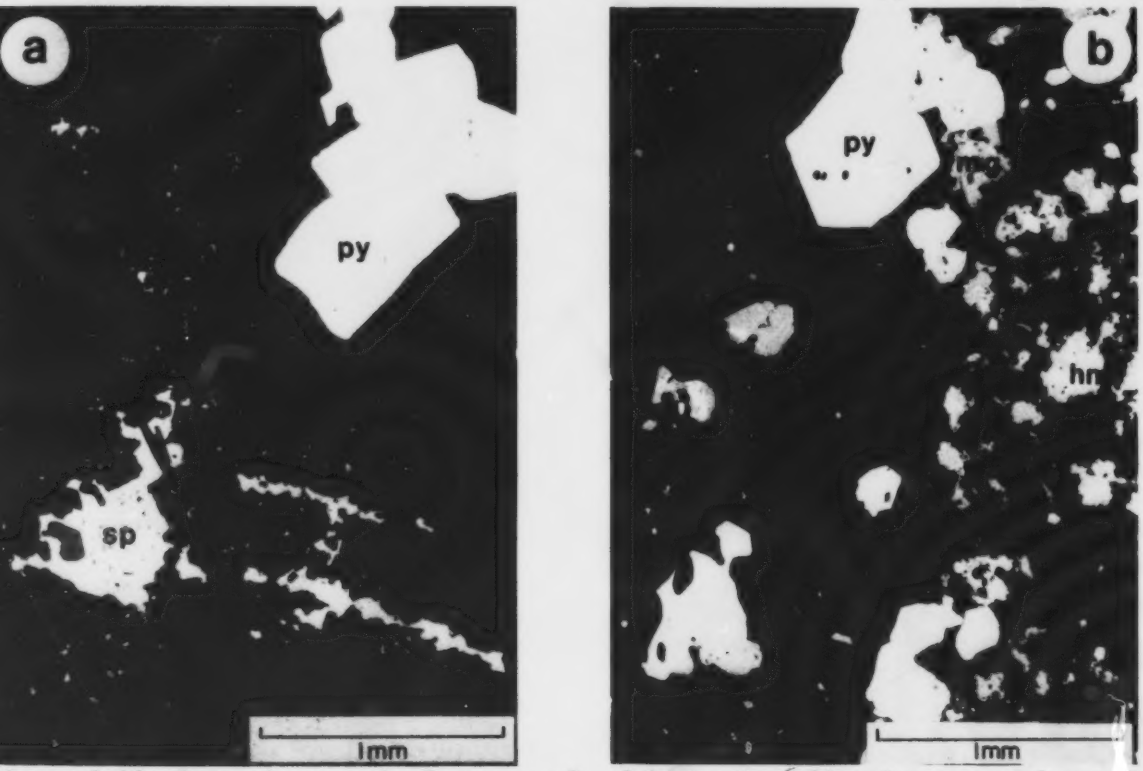


Figure 2-10. Some microscopic features of sulphide mineralization near Gabarus Bay (over).

a. Pyrite (py) cubes plus anhedral-subhedral sphalerite (sp) containing exsolved(?) blebs of chalcopyrite (Irish Brook area).
b. Pyrite octahedra plus anhedral magnetite-hematite (mg-hm, Gull Cove).
c. Scattered pyrite cubes with localized anhedral chalcopyrite (cp, Gull Cove) (over).
d. Coarse pyrite with rare blebs of bornite (bn, Cape Gabarus) (over).

Bornite and pyrrhotite are extremely rare, with bornite occurring as occasional tiny inclusions within pyrite and gangue (Fig. 2-10d) and pyrrhotite as small rounded blebs within pyrite.

Spectrographic scans of six hand-picked samples of mineralization from these occurrences (Table 2-3) suggest that Cu values are generally less than about 0.03%, Mn is present in some samples in concentrations up to 0.5%, and trace amounts of Pb and possibly Mo are present in a few samples.

MACINTYRE LAKE

There is an interesting occurrence of mineralization at MacIntyre Lake which lies some 10 km southwest of Gabarus Bay (Fig. 0-1) and hence outside of the mapped area. However, as the host rocks resemble those around Gabarus Bay with patches of Carboniferous rocks resting unconformably upon the Fourchu Group, this occurrence was also briefly examined and sampled. Previous investigations included pitting, trenching and mapping by New Jersey Zinc Company (McNamee, 1957), and limited diamond-drilling by Kennco Limited (Pérusse, 1960). Thin pockets of conglomerate and grit, overlain by brown limestone assigned to the basal Windsor Group, which unconformably overlie schistose lithic tuffs of felsic and intermediate compositions belonging to the Fourchu Group, occur around the western and southwestern end of the lake (Fig. 2-12).

Table 2-3. Results of emission spectrographic scans of selected pyritic mineralization.

	%							
Sample	<.001	.001-.0033	.0033-.01	.01-.033	.033-.1	.1-.5	.5-1	>1
IRISH BROOK								
F16-8045B	Be,Yb	Ag	Y,Ni Co,Sc	V,Cr,Zr Cu,Sr	Ba	Mn	Ti	Si,Al,Fe Mg,Ca,Na
F16-8170B	Be,Yb Ag	Cr,Ni	Y,Co Sc	Zr,Ba	V Sr		Cu Ti	Si,Al,Fe,Mg Ca,Na
GULL COVE								
F16-9046B	Be	Yb,Ag Ni	Cr,Y,Co Sc	Zr,Cu	V,Sr Ba		Ti	Si,Al,Fe,Mg Ca,Na
F16-9048B	Be,Yb Ag	Y,Cu Ni	Cr,Co Sc	V,Zr Sr	Ba		Ti	Si,Al,Fe,Mg Ca,Na
CAPE GABARUS								
F16-8106A	Be,Yb V	Mn,Y Ag,Sc Sr	(In??) Cr,Ni	Mo?,Mg Pb,Zr,Sc Ba	Ca,Co	Al Ti		Si,Fe
F16-8106B	Be,Yb Ag	Y,Ni Co	(In??)Mo? V,Mn,Sc Sr	Cr,Cu Ba	Mg,Zr	Ca	Ti	Si,Al,Fe, Na
WINGING POINT								
F16-8107B	Be,Yb Ag	Cr,Cu Ni	Y,Co Sc,Ba	V,Zr	Sr	Mn	Ti	Si,Al,Fe,Mg, Ca,Na
FOURCHU ROAD								
F16-8164B	Be,Yb Ag,Co	Cr,Ni Sc	V,Y	Zr,Cu Sr	Mn Ba	Ti		Si,Al,Fe,Mg, Ca,Na
MACINTYRE LAKE								
F16-8200	Be,Yb Ag	Cr,Ni	Y,Co Sc	V,Zr	Sr	Cu	Ti Ba	Si,Al,Fe,Mg, Ca,Na
F16-8201	Be,Yb Ag	Cr,Ni	Y,Co Sc	V,Zr		Ti Zn Sr	Cu	Si,Al,Fe,Mg, Ca,Na,Ba

If not listed above not detected, but if present:

<1%	P, Na
<.1%	As, W, Ta
<.05%	U, Zn
<.033%	Tl, Th, Ce
<.01%	B, Ge, Sb, Nb, In, Pb, Nd, La
<.005%	Mo,Sn,Bi
<.0033	Ga

Laboratory for the Investigation of Minerals

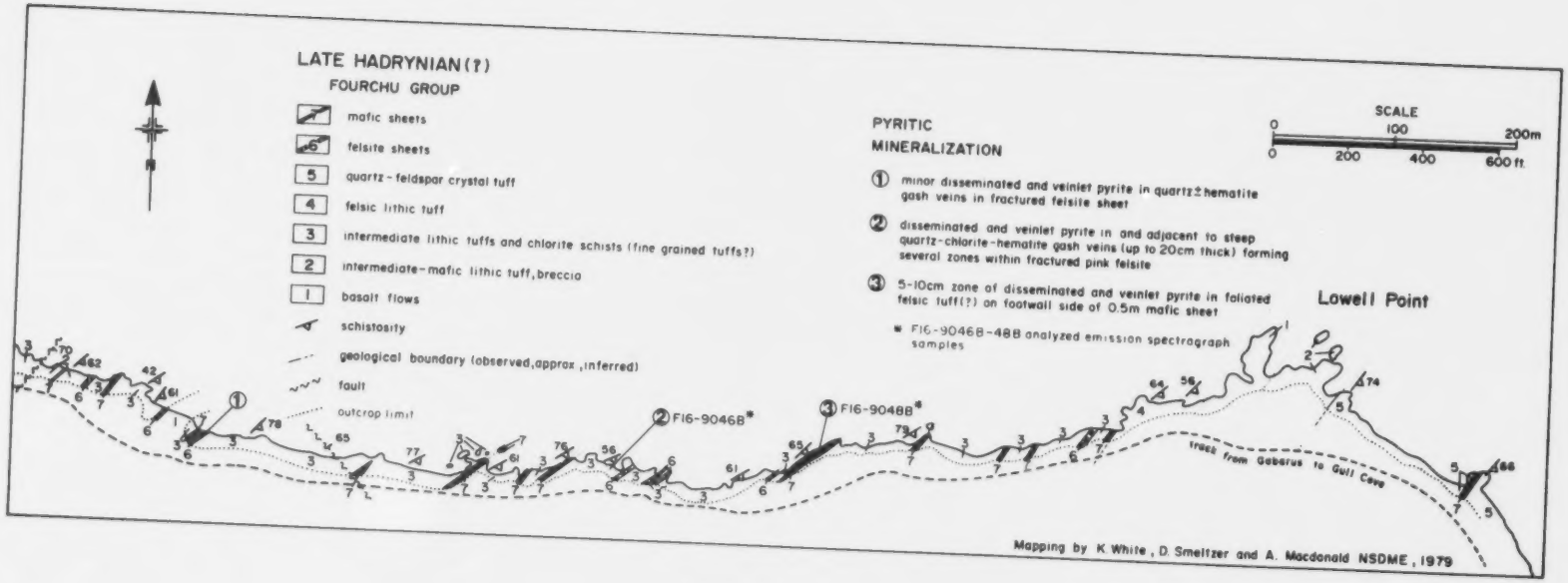

LATE HADRYNIAN(?)
FOURCHU GROUP
mafic sheets
felsite sheets
5 quartz-feldspar crystal tuff
4 felsic lithic tuff
3 intermediate lithic tuffs and chlorite schists (fine grained tuffs?)
2 intermediate-mafic lithic tuff, breccia
1 basalt flows
schistosity
geological boundary (observed, approx., inferred)
fault
outcrop limit
PYRITIC MINERALIZATION
① minor disseminated and veinlet pyrite in quartz±hematite gash veins in fractured felsite sheet
② disseminated and veinlet pyrite in and adjacent to steep quartz-chlorite-hematite gash veins (up to 20cm thick) forming several zones within fractured pink felsite
③ 5-10cm zone of disseminated and veinlet pyrite in foliated felsic tuff(?) on footwall side of 0.5m mafic sheet
* FI6-90468-488 analyzed emission spectrograph samples
SCALE
0 100 200m
0 200 400 600 ft.
Lowell Point
FI6-90468*
FI6-90488*
trace from Gabrus to Gull Cove
Mapping by K. White, D. Smeltzer and A. Macdonald NSDME, 1979

Figure 2-11. Detailed geological map of Gull Cove pyrite showings, Gabrus Bay, Fourchu belt.

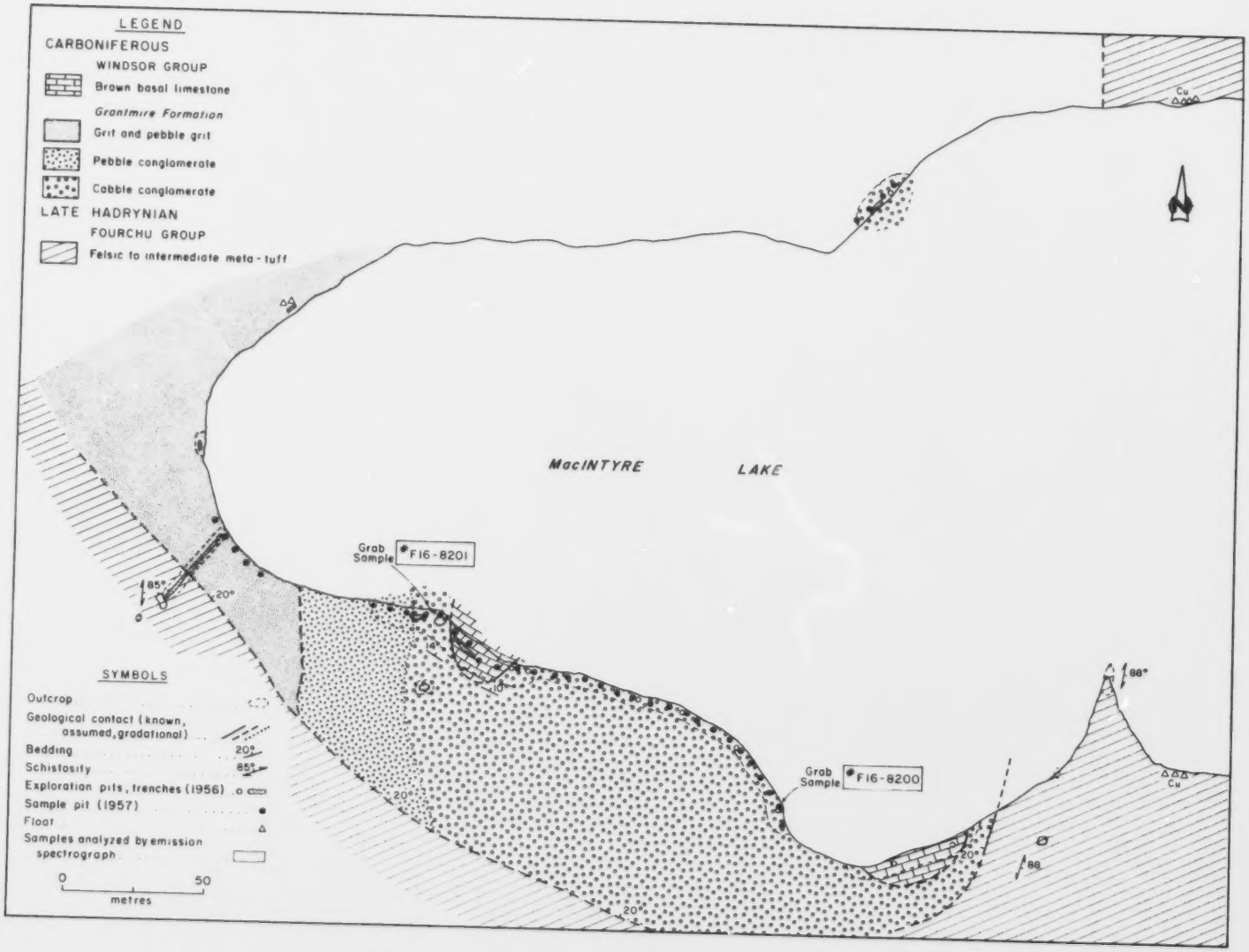


Figure 2-12. Detailed geological map of McIntyre Lake chalcopyrite showing (after Perusse, 1960), Fourchu belt.

The mineralization consists of disseminations of pyrite and lesser chalcopyrite and malachite, with small amounts of sphalerite and galena also having been reported (Perusse, 1960). It is essentially restricted to the matrix of the conglomerate, which is partly cemented by medium grained calcite. This calcite is a gangue mineral and the mineralization as a whole appears to be introduced, although Perusse (1960) suggested that it could have been sedimentary in origin. Spectrographic analyses of two samples of mineralized matrix material indicate Cu values about 0.5% and Ba values about 1%, and one sample contained, in addition, 0.1-0.5% Zn (Table 2-3).

PART 3: STIRLING AREA

INTRODUCTION

The Stirling area (or Mira-L'Ardoise belt of Weeks, 1954) was selected for study because this belt of volcanic, volcaniclastic and epiclastic rocks hosts volcanogenic massive sulphide mineralization near Stirling, and also numerous pyritic showings elsewhere along the belt (Fig. 0-1).

These rocks were assigned by Weeks (1954) to the Bourinot Group of Middle Cambrian age. However, as a result of a radical stratigraphic re-interpretation southwest of the Mira River, Smith (1978) renamed these rocks the Giant Lake Complex and correlated them with the Fourchu Group of Hadrynian(?) age. In this study, this group of rocks will be informally referred to as the Stirling volcanic belt because sequences typical of the group are exposed in the vicinity of Stirling. Although this belt is probably a time correlative of the Fourchu Group, it will be shown that there are some significant differences between these two groups of rocks.

Purposes of the study were: (1) reconnaissance stratigraphic and petrologic subdivision of the volcanic and related rocks of the belt, (2) determination of the nature and geological setting of the various pyritic occurrences and (3) a comparison of these rocks with those of the Fourchu Group with which they have been equated (Smith, 1978; Keppie, 1979).

Three separate blocks along strike of the belt were mapped (Fig. 0-1). Two of these, covering an area of approximately 60 km^2, were located northeast and southwest of Stirling and mapped at a scale of 1:15 840. The third block was chiefly a coastal strip extending some 7 km east-northeast from Point Michaud to Red Head and was mapped at a scale of 1:4800.

The belt as a whole has subdued relief with elevations rarely exceeding 60 m that combined with an extensive cover of drift, precludes good rock exposure except along the shoreline and intermittently along the courses of the rivers and larger brooks.

Relatively recent geological work in the area includes regional mapping of the whole area (at a scale of 1:63 360) by Weeks (1954), a petrographic study of the volcanic rocks near Stirling (Wilband, 1962) and mapping (1:50 000) of the area between Giant Lake and the Mira River (Smith, 1978).

The Mindamar Zn-Pb-Cu sulphide deposit near Stirling, which has been the main focus of economic interest in the belt, was orginally described as an epigenetic replacement deposit (e.g. Cairnes, 1917; Watson, 1954). Recognition of the deposit as being mainly volcanogenic in origin (e.g. Poole, 1974) was presumably responsible, in part, for renewed exploration interest in the rocks of the belt (e.g. by St. Joseph Explorations Limited, 1975 and by Cominco Limited, 1975-1980). Mapping in the vicinity of the abandoned Mindamar Mine by Cominco Limited (Hunter and Anderson, 1975; Roscoe, 1975) resulted in subdivisions of the volcanic, volcaniclastic and related epiclastic rocks that were later applied to the whole belt (Mosher, 1979). Furthermore, a detailed study (Miller, 1979) of all surviving core from the mine has clearly defined the nature, geological setting and environment of deposition of this deposit, thus providing a useful

exploration guide to other possible occurrences.

LITHOLOGICAL DESCRIPTIONS

STIRLING VOLCANIC BELT (FOURCHU GROUP?)

The Stirling volcanic belt, which outcrops within a 50 km long belt extending southwestward from near Mira River to L'Ardoise on the southeast corner of Cape Breton Island (Fig. 0-1), contains a wide variety of metamorphosed volcanic, volcaniclastic and epiclastic rocks which have been intruded by an abundant suite of mafic sheets and by several granitoid plutons and related dyke rocks. Subdivision within the areas of reconnaissance mapping along the strike of the belt indicates that the relative volumes of mafic intrusive, volcanic, pyroclastic and epiclastic rocks present are approximately 5%, 30%, 50% and 15% respectively. Volcanic and pyroclastic rocks thus dominate the sequence, however there appears to be a gradual change along strike from southwest to northeast from predominantly volcanic to predominantly pyroclastic. It is not known if there are any repetitions of major units as a result of very large-scale folding although relatively large-scale fold structures can be recognized within epiclastic enclaves.

Intermediate-Mafic Lavas

Intermediate-mafic lavas occur near Stirling and the Caledonia Road in the northern part of the mapped belt (Fig. 3-1, in map pocket) and near Point Michaud in the southern part (Fig. 3-2). The best exposures are in the latter area.

The lavas, which include both flows and flow breccias, are of uncertain thickness. Locally they are at least 200 m thick, if not repeated by folding. In general, they are dark green to purple-green, locally vesicular to amygdaloidal, sparsely porphyritic rocks which tend to be highly fractured or sheared and calcite-veined. They grade locally into flow breccias and coarse lithic tuffs and are extensively intruded by concordant and crosscutting mafic sheets.

Texturally, these rocks vary from very fine grained flow-banded to fine grained subophitic, with sparse plagioclase phenocrysts strongly saussuritized and sericitized in groundmasses of albite laths (mainly An_{6-11}), chlorite, epidote, calcite, quartz and opaques (Fig. 3-3a). Where present, amygdules have zoned infillings of chlorite, epidote, calcite and less commonly pumpellyite and zeolites. In a few examples, the igneous fabric is lost and these rocks consist of weakly foliated assemblages of tremolite-actinolite, chlorite, plagioclase, calcite, quartz and opaques.

Chemical analyses of five samples show the lavas to be mainly basalts and basaltic andesites (Table 3-1).

Mafic Sheets

Mafic sheets are widely distributed throughout the belt, cutting all the metavolcanic and related rock types. The sheets vary considerably in size, from less than a metre to more than 50 m wide. Whereas many appear to be conformable with the prevailing structural trend, others are clearly crosscutting, as observed between Point Michaud and Collins Point (Fig. 3-2) where basaltic andesites and associated slumped and infolded sedimentary rocks are extensively injected by the mafic sheets, and in diamond-drill core from the Stirling area (Fig. 3-4).

These mafic sheets are generally dark greenish rocks ranging from fine grained sparsely porphyritic basalt,

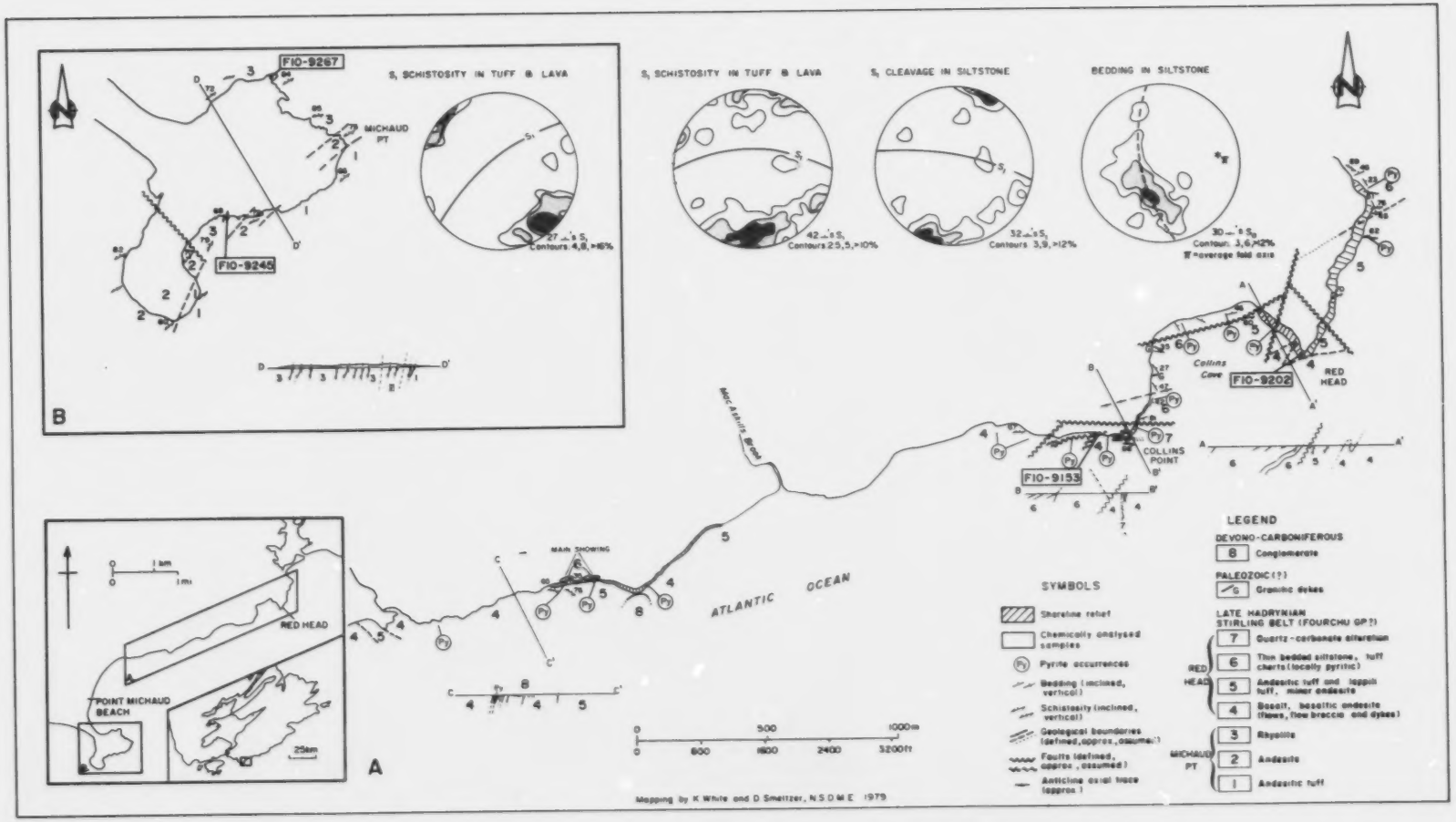


Figure 3-2. Geological map of Point Michaud area.

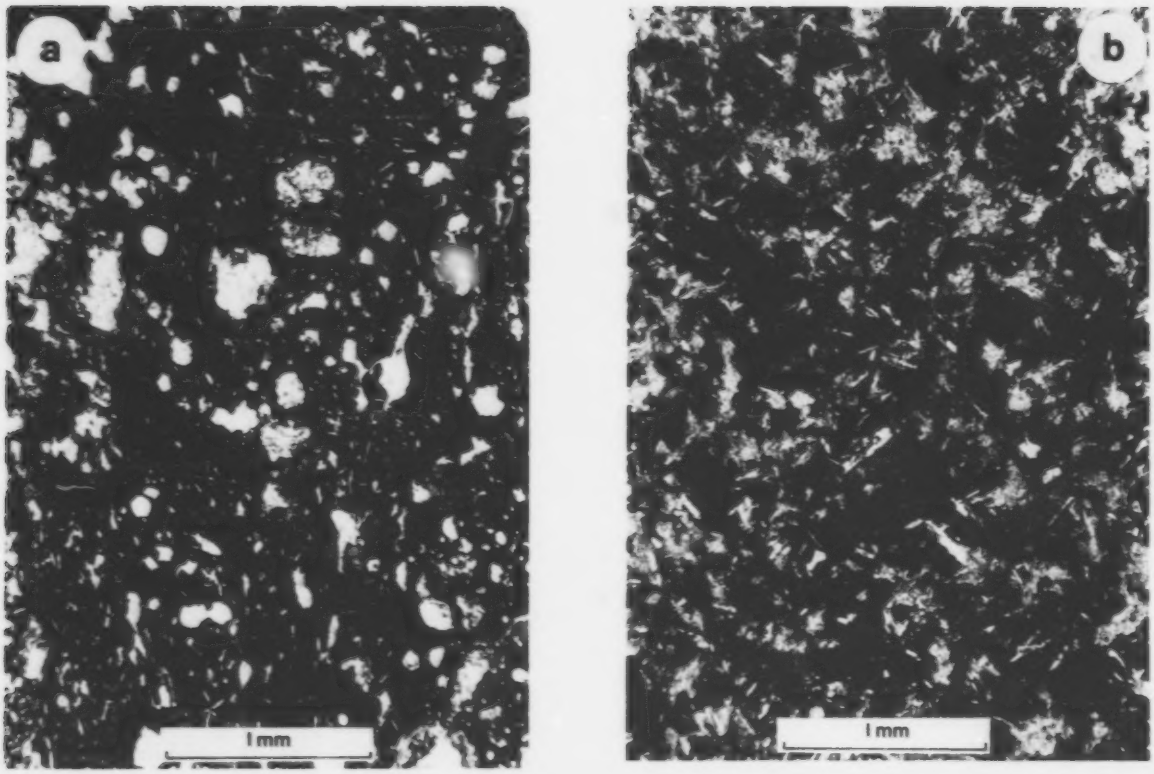


Figure 3-3. Petrographic features of volcanic and intrusive rocks of Stirling Group.

a. Vesicular basalt flow.

b,c,d. Basalt, diabase and gabbro intrusive sheets (b, c over).

e,f. Quartz-feldspar porphyritic rhyodacite flows (over).

g. Quartz-feldspar augen schist (rhyodacite flow or crystal tuff?) (over).

h. Feldspar porphyritic dacite (over).

c
1 mm

d
1 mm

e
1 mm

f
1 mm

through medium grained more strongly porphyritic diabase, to medium- to coarse-grained more equigranular gabbro. They tend to be massive and relatively uniform in appearance, lacking obvious penetrative foliation although locally fracture-cleaved.

In thin section (Figs. 3-3b to d), they generally contain phenocrysts of andesine (An_{29-34}), commonly partially pseudomorphed by epidote, chlorite and sericite. Pseudomorphs of calcite, chlorite and hematite after possible mafic phenocrysts, in groundmasses of sericitized feldspar, chlorite, epidote, calcite, limonite or possibly leucoxene are also common. A few contain tremolite-actinolite and clear, possibly metamorphic oligoclase. The more equigranular gabbros consist of altered plagioclase and intergrowths of tremolite-actinolite and chlorite possibly after amphibole, interstitial quartz and oxidized opaques with disseminations and veinlets of epidote and(or) calcite.

Both petrographically and in outcrop, these mafic sheets, especially the finer grained bodies and facies, are not easily distinguished from the intermediate-mafic lavas. However, chemical comparisons discussed below suggest that they are significantly different in composition.

Felsic Lavas

Two types of porphyritic felsic lavas occur in the belt, uncommon feldspar porphyritic dacites and abundant quartz-feldspar porphyritic rhyodacites.

Feldspar Porphyritic Dacites

The dacites are very restricted in

Table 3-1. Geochemical analyses of volcanic and related intrusive rocks of the Stirling belt.

MAJOR OXIDES %	BASALT DIABASE SHEETS			BASALT AND ANDESITE FLOWS					RHYODACITE FLOWS					
SAMPLE NUMBER	F10-8504	F09-8042	F10-8512	F10-9153	F10-9202	F09-8018	F09-8036	F09-8024	F10-8530	F09-8526	F09-8027	F09-8009	F10-9295	F10-9267
Silica	46.20	47.09	50.47	49.23	50.98	52.21	53.36	53.98	70.34	72.89	73.15	73.35	73.71	76.87
TiO_2	0.85	0.97	1.30	1.14	1.24	1.20	0.92	0.48	0.48	0.27	0.28	0.23	0.48	0.13
Al_2O_3	17.11	13.17	14.09	20.94	18.33	18.72	17.01	15.63	12.53	13.59	13.54	12.80	13.18	11.44
Fe_2O_3	2.38	2.29	2.59	1.04	1.20	2.56	2.43	2.72	2.10	0.23	0.50	1.21	1.02	0.27
FeO	6.66	7.19	6.06	7.43	7.33	5.77	6.96	4.12	2.93	2.00	2.25	2.10	1.15	0.79
MnO	0.14	0.16	0.17	0.14	0.15	0.11	0.11	0.12	0.06	0.04	0.05	0.05	0.10	0.02
MgO	12.31	12.32	10.93	4.95	6.46	3.45	6.39	7.31	1.55	1.16	1.20	1.00	0.80	0.20
CaO	8.15	12.47	10.13	6.43	3.69	7.04	3.57	6.93	2.68	0.85	2.10	1.15	1.37	0.41
K_2O	0.35	0.33	0.43	1.52	0.12	1.97	0.90	0.51	0.58	0.61	2.50	1.39	1.56	3.47
Na_2O	2.24	1.30	2.83	3.15	4.86	2.69	4.29	4.03	4.13	6.35	3.25	4.33	4.94	4.40
H2O+	3.77	3.06	1.15	3.52	4.31	2.94	3.83	2.65	1.50	1.25	1.13	1.06	0.96	0.68
H2O-	0.00	0.05	0.00	0.00	0.00	0.01	0.01	0.04	0.00	0.00	0.00	0.01	0.00	0.00
P_2O_5	0.16	0.14	0.17	0.21	0.37	0.28	0.11	0.16	0.11	0.10	0.11	0.10	0.13	0.09
CO_2	0.34	0.05	0.04	0.14	0.05	0.64	1.14	0.30	0.50	0.02	0.05	0.14	0.05	0.02
TOTAL OXIDES	100.66	100.59	100.35	99.85	99.09	99.59	101.03	98.98	99.49	99.35	100.61	98.91	99.45	98.79
TOTAL IRON AS Fe_2O_3	9.78	10.28	9.32	9.30	9.35	8.97	10.16	7.30	5.36	2.45	3.50	3.54	2.30	1.15
TRACE ELEMENTS (ppm)														
Be	86	51	92	400	150	640	120	210	185	140	530	290	530	700
Rb	6	9	8	42	2	79	16	8	8	8	73	30	50	47
Sr	308	122	550	570	340	465	115	500	134	128	100	68	190	110
Zr	60	105	88	105	110	185	75	63	100	248	210	220	280	400
F	210	140	410	320	390	460	310	410	190	160	280	600	460	250
Li	18	16	10	12	19	11	25	13	12	8	6	13	15	6
Y	15	15	18	27	14	30	14	16	22	18	30	25	18	28
Sn	1	4	1	2	3	2	1	1	1	2	2	4	3	7
Cu	89	82	1	125	82	63	26	49	15	-1	4	60	49	11
Mo	3	4	2	4	4	3	3	3	4	3	3	4	4	3
Pb	4	78	5	60	10	6	4	7	2	4	4	13	250	8
Zn	90	135	102	211	91	88	96	62	55	54	39	66	1230	25
Ag	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bi	0.1	0.1	0.1	0.1	0.1	0.3	0.1	0.1	0.3	0.1	0.1	0.4	1.0	0.3
S	1580	1700	120	280	1880	400	60	100	200	580	60	160	3580	80
Co	53	57	38	26	28	20	27	26	7	1	3	3	-1	-1
Ni	195	133	100	22	45	12	22	50	7	1	1	4	5	2
Cr	380	450	390	22	36	24	38	175	33	30	22	20	20	34

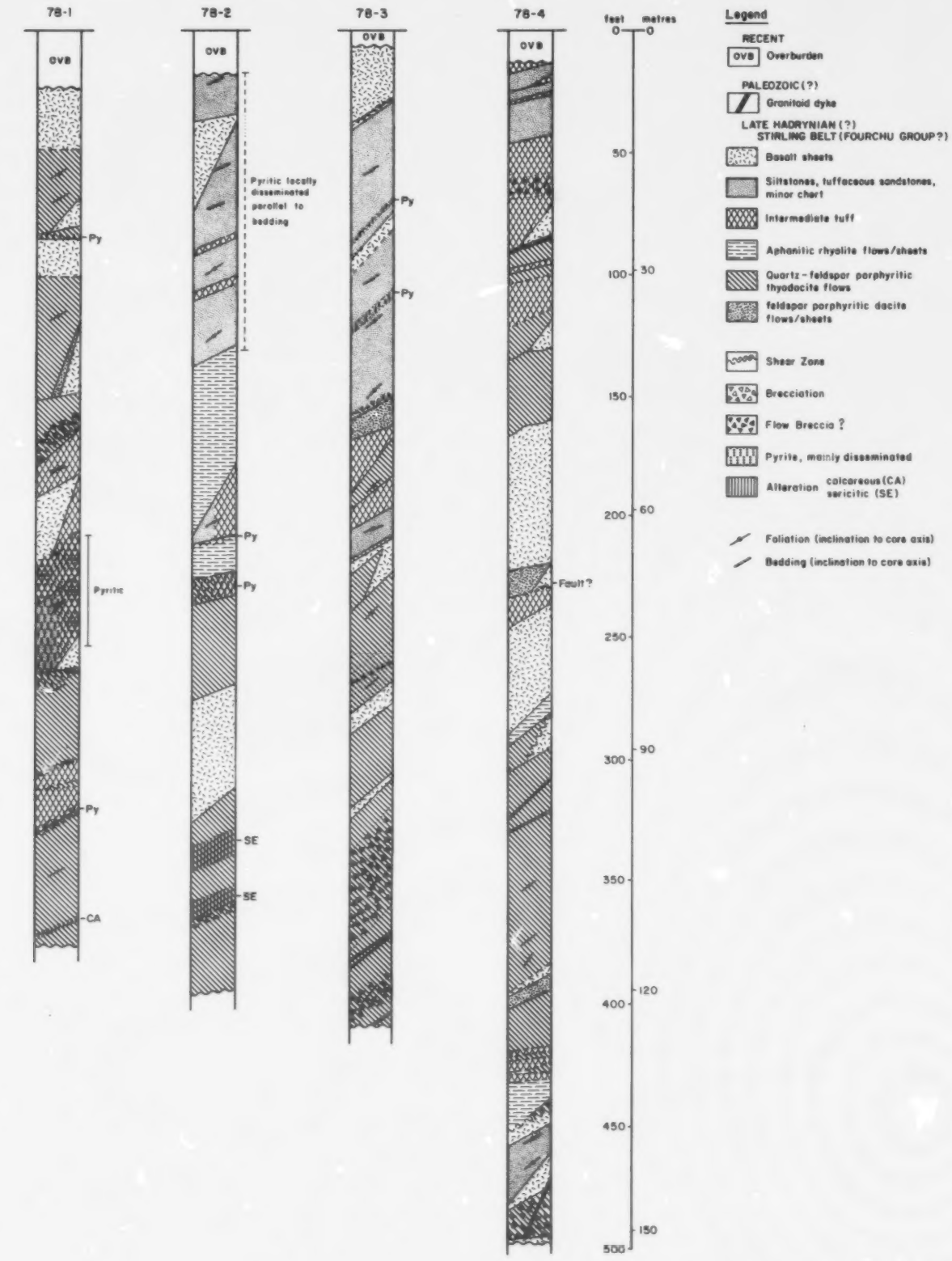


Figure 3-4. Summary of drill core data from Stirling area.

distribution and thickness, individual occurrences never exceed a few tens of metres thickness. In the Caledonia Road area they occur within felsic lithic tuffs at several localities. Though not reported from the Mindamar mine at Stirling (Miller, 1979), they have been observed in drill core from that general area associated with the quartz-feldspar rhyodacites. South of Stirling there are rare occurrences, found only at a few localities, associated with schistose intermediate tuffs.

In general appearance, they are medium grey to greenish aphanitic rocks, with small phenocrysts of feldspar, either massive or weakly schistose. In thin section, they are seen to be moderately to highly altered. The plagioclase phenocrysts, which are intensely altered to saussurite and sericite, are set in groundmasses of aligned albite laths (An_{6-8}), chlorite, sericite, quartz, orthoclase(?), calcite and oxidized magnetite (Fig. 3-3h). Sparsely distributed aggregates of chlorite, sericite and opaques may be pseudomorphs after biotite. Texturally, they are hiatal porphyritic with very fine grained pilotaxitic groundmasses on which a sericitic tectonic foliation is locally superimposed subparallel or oblique to the flow banding. Calcite-sericite seams and anhedral disseminations are pervasive features.

From their widespread, but minor, occurrence and close association with a wide variety of other rock types, it is possible that these dacites occur wholly or in part as intrusive sills and sheets rather than as flows.

Quartz-Feldspar Porphyritic Rhyodacites

The rhyodacites generally occur in thick, widely distributed units (Fig. 3-1). These units may reach thicknesses of hundreds of metres and may in part be domal subvolcanic bodies. The thickest and most extensive units occur between Framboise and St. Esprit, on Point Michaud, and near Stirling where a large elongate body, 200-300 m thick by 4 km long, occurs together with several smaller satellite bodies (Hunter and Anderson, 1975; Roscoe, 1975). In contrast, in the Caledonia Road area the rhyodacites are restricted to minor thin flows or sheets associated with felsic lithic tuffs.

The rhyodacites are grey to greenish or buff, strongly porphyritic rocks, generally massive or weakly schistose and never vesicular or amygdaloidal. In the Framboise-St. Esprit area, the more western of the two large felsic bodies is much more strongly schistose, but this body may be composed of quartz-feldspar crystal tuff rather than porphyritic rhyodacite.

In thin section, the rhyodacites are seen to be hiatal porphyritic with large (<6-8 mm) rounded and resorbed quartz phenocrysts and zoned albitic plagioclase (An_{7-14}) phenocrysts which tend to be moderately sericitized, in very fine grained quartz-feldspathic matrices together with chlorite, sericite $\pm$ epidote and calcite (Figs. 3-3e, f). Accessories include apatite and opaques (magnetite $\pm$ hematite $\pm$ pyrite). Some small chloritic aggregates may represent pseudomorphs after biotite - if so, biotite must have been a very minor component (< 5%). Evidence of internal deformation varies from undulose extinction through pull-apart structures to strong brecciation. Calcite, where present, tends to occur in pressure shadows, tension gashes and fracture fillings. Some of these deformational effects may actually be composite in nature, produced by both flow (autobrecciation) and tectonism. Some closely related deformed rocks (Fig. 3-3g) contain so many fragmented crystals set in

foliated sericitic groundmasses with local chloritic laminae that they could represent crystal tuffs identical in composition and provenance to the quartz-feldspar porphyritic rhyodacites.

Tuffs

A variety of foliated intermediate to felsic tuffs, including phyllites (suspected of having been derived from fine grained tuffs or ashes) occur within the areas studied. Although distributed throughout the area, they are most abundant in the northeastern part of the belt, between Caledonia Road and Giant Lake (Fig. 3-1), reflecting a gross change in the geology along strike from predominantly volcanic to predominantly tuffaceous.

In the field, two main types were distinguished, felsic lithic tuffs and calcite-chlorite phyllites and schists.

Felsic and Intermediate Lithic Tuffs

Lithic tuffs generally appear massive in outcrop, with internal banding and foliation either absent or only weakly developed. The felsic tuffs are greyish-green to buff rocks containing small lapilli (generally 1-2 cm) of pink and green felsite and porphyritic rhyodacite in fine grained, pale greenish matrices. The intermediate lithic tuffs are darker grey-green and contain coarser lapilli of green and purple andesite and dacite. Locally, they grade into volcanic wacke.

In thin section, the lithic tuffs contain abundant angular volcanic fragments together with variable amounts of fractured, subangular quartz and(or) sericitized feldspar crystals in foliated very fine grained mixtures of quartz, feldspar, sericite, chlorite, calcite and epidote. In a few samples, moderately close packing and flattening of lapilli are suggestive of welding. However, the bulk of these rocks appear to be air-fall lithic tuffs. The proportion of crystals to lithic lapilli differs from sample to sample and hence there may be local gradations into crystal tuffs, although such gradations were not observed in the field.

Calcite-Chlorite Phyllites and Schists

These are grey-green, fine- to medium-grained phyllites and schists which occur as thin layers and lenses up to a few metres thick marginal to or within basaltic andesite sequences and also interbedded with felsic and intermediate lithic tuffs. They are thought to represent fine grained tuffs or ashes of essentially intermediate composition, although they could also be fine grained epiclastic rocks.

In thin section, they are seen to consist of small, highly altered lithic fragments and possible shards in fine grained foliated matrices of chlorite, calcite, epidote, sericite, quartz, feldspar and opaques.

Epiclastic Rocks

Volcanic Wackes

Volcanic wackes occur as a thick accumulation in the vicinity of Giant Lake and MacMullin Lake (Fig. 3-1). Elsewhere (near Pt. Michaud, Stirling and Caledonia Road), they are apparently restricted to individual beds within finer grained epiclastic sequences. They occur as thickly bedded, green to purple, medium- to coarse-grained wackes displaying locally developed scours, graded bedding and rip-up clasts.

In thin section they are seen to contain abundant matrix-supported lithic clasts of subangular aphanitic and devitrified volcanic material of overall intermediate to felsic composition together with up to about 15% subangular quartz and altered

feldspar grains in fine- to medium-grained matrices (up to 20%) of chlorite, calcite, quartz, feldspar, sericite and finely broken up lithic and crystal debris (Figs. 3-5c, d). Crosscutting epidote veins occur locally.

Siltstones

There are at least three main occurrences of siltstones within the belt, apparently within the cores of large-scale folds:

(1) Caledonia Road - Northeast Framboise River,

(2) Mindamar Mine area, Stirling,

(3) Collins Point - Red Head, Point Michaud

They occur in relatively thick sequences (up to 200-300 m), which are typically thinly bedded to laminated and commonly display small-scale sedimentary structures (slumps, scours, grading, etc.). Although they are predominantly grey siltstones they are locally interbedded with greenish-grey chert and occasional beds of volcanic wacke. Disseminated pyrite is very common, usually as sparse stratabound concentrations, but locally concentrated into thin, mainly stratiform, layers. Although cleavage is locally well developed, these rocks generally do not appear to have been metamorphosed.

In thin section, they are found to consist of very fine- to fine-grained quartz, feldspar, chlorite, sericite, epidote, calcite and opaques (mainly pyrite), with occasional large rounded quartz and rarer altered feldspar clastic grains (Fig. 3-5a, b). Small-scale sedimentary grading, slumping and scour structures are common. Pressure shadows are commonly produced in the lee of large quartz grains and larger pyrite cubes, and fine sericite is commonly aligned within closely-spaced cleavage planes. The heaviest pyrite concentrations occur in the finer grained, generally more epidotic laminae. The pyrite ranges from very fine grained globular clusters (framboids) to cubes of various grain sizes and the larger cubes overgrow the siltstone fabric.

Carbonate Rocks

Local minor occurrences of carbonate rocks were noted within the mapped areas of the belt (Figs. 3-1, 3-2). As similar rocks occur in the footwall of the Mindamar Mine at Stirling and have been described as chemical precipitates (Miller, 1979), special attention was paid to the modes of occurrence and mineralogies of these rocks.

In appearance, they are cream to buff, fine- to medium-grained crystalline rocks, commonly weathering to an intense orange. They vary from massive to schistose, although locally they may be brecciated. In general, they occur as conformable bands and lenses up to tens of metres thick within tuffs or siltstones or both, or adjacent to quartz-feldspar porphyritic rhyodacites/crystal tuffs (Fig. 3-1, 3-2). However, one of the occurrences near Collins Point (Point Michaud area) was clearly produced by crosscutting alteration of siltstone and is therefore of secondary replacement origin.

The carbonate rocks consist largely of fine grained granoblastic dolomite with frequent patches and veinlets of medium- to coarse-grained calcite, and patches and laminae of very fine grained quartz, possibly recrystallized chert (Figs. 3-5e, f). Some of the more schistose varieties also contain thin lenses and laminae of very fine grained talc(?) (Fig. 3-5g). Occasionally isolated subangular clastic quartz grains occur in the carbonate matrix. In the more schistose samples, such grains tend to

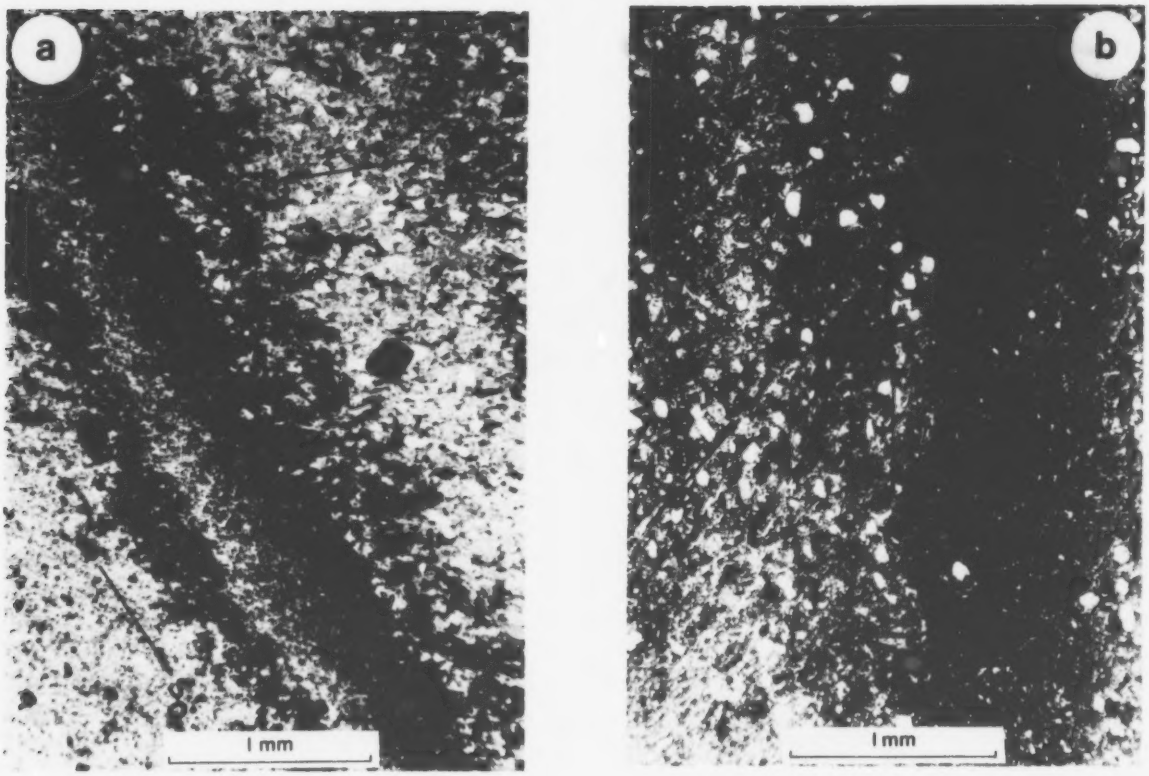


Figure 3-5. Petrographic features of epiclastic and carbonate rocks of Stirling belt.

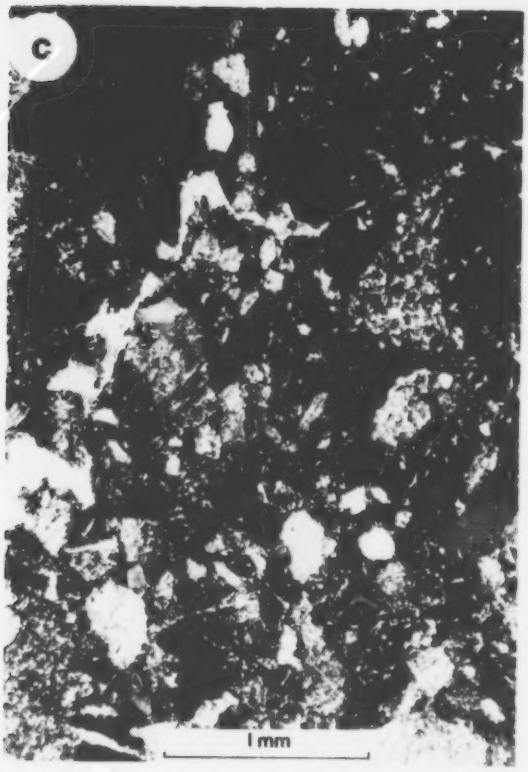
a,b. Thin bedded siltstones showing slaty cleavage, minor euhedral pyrite (black) with pressure shadows.

c,d. Volcanic wackes (c) with large embayed quartz clast (d) (over).

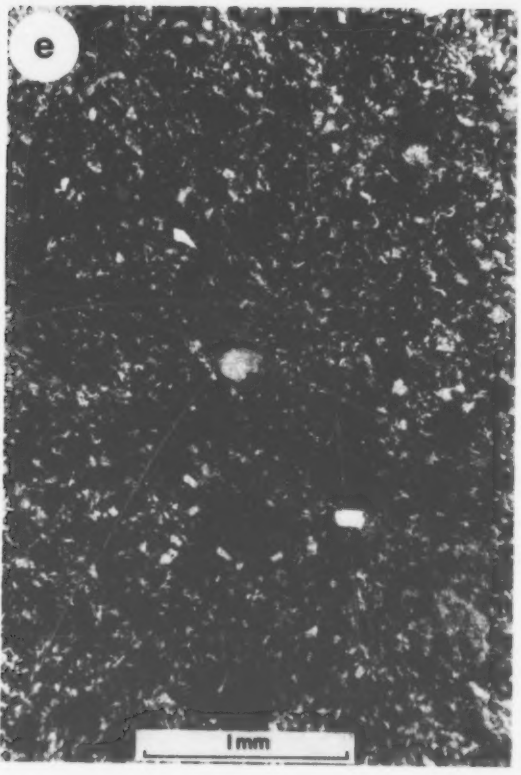
e. Fine grained dolostone containing sparse quartz grains (over).

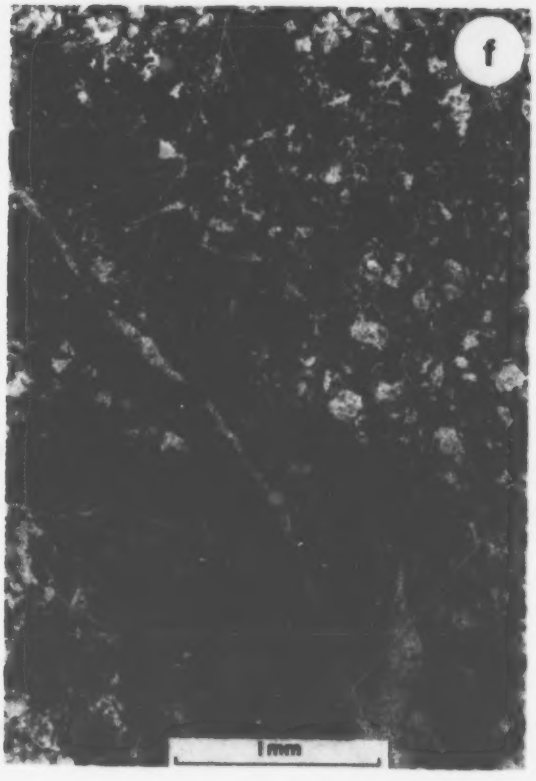
f. Sheared pyritic (black) dolostone (over).

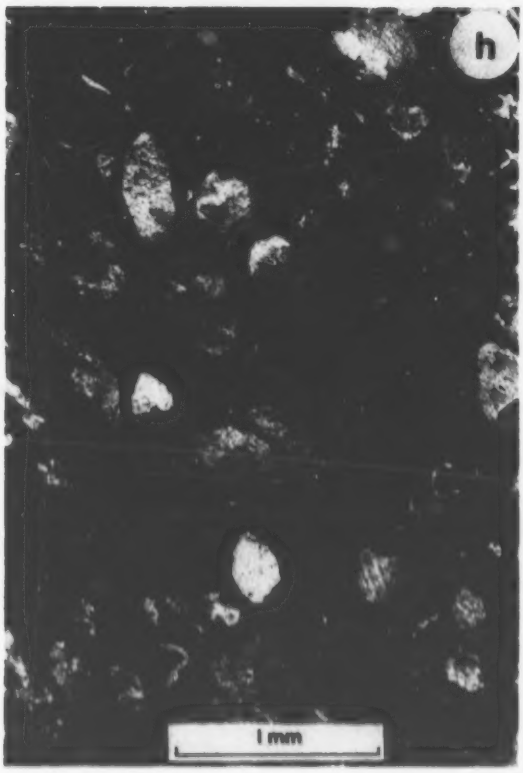
g. Carbonate schist containing dolomite, calcite, quartz and minor talc. Deformed pisolitic(?) dolostone (over).


c
1 mm

d
1 mm


e
1 mm


f
1 mm



be strained and pulled apart. Accessory minerals include epidote, chlorite, sericite and opaques. Some samples contain minor thin siltstone bands or laminae and one sample apears to have a pisolitic carbonate texture (Fig. 3-5h).

Although magnesite is reported from the footwall carbonate rocks at the Mindamar mine (Watson, 1954; Miller, 1979) x-ray diffraction (XRD) analyses of six samples from these other occurrences showed that they contain only dolomite, calcite and quartz in varying proportions as their main constituents.

SEDIMENTARY COVER ROCKS (KELVIN LAKE FORMATION)

A predominantly red sequence of younger clastic sedimentary rocks, occupying a downfaulted synclinal trough, unconformably overlies the meta-volcanic and metasedimentary rocks of the Stirling belt (Fig. 3-1). The bulk of these rocks were originally labelled the Middle River Group and assigned a Silurian-Devonian age by Weeks (1954), but more recently they have been re-named the Kelvin Lake Formation and assigned an Early to Middle Cambrian age by Smith (1978) and Keppie (1979).

Most of these rocks are unmetamorphosed, with the exception of a hornfelsed sequence adjacent to Capelin Cove Pluton in South Brook near Framboise Intervale, but they have all been folded into open folds, approximately coaxial with those developed in the more tightly folded metamorphic basement.

Incomplete sections across the contacts between these clastic cover

rocks and their underlying metamorphic basement were observed at six different locations between Currie Lake and Middle Framboise River (Fig. 3-1). Although local variations in rock types and in their proportions are common, it is possible to generalize their stratigraphy as follows:

Top

(3) massive, reddish to orange, coarse arkosic sandstone, minor thin grey quartzitic sandstone (5-30 cm beds) and maroon to reddish siltstone (10-40 cm beds).

(2) massive, reddish, quartz-pebble arkosic grit,

(1) massive, purple to brown, polymictic conglomerate and minor interbedded wacke (up to 2.5 m beds),

Base

The conglomerate is varied in colour, and in clast shapes, sizes and compositions, apparently reflecting provenance, local or otherwise. Where actually observed in unconformable contact with the underlying metamorphic rocks, the basal conglomerate is dark purplish and contains mainly locally derived subangular to well rounded pebbles of felsic to intermediate metavolcanic rocks and vein quartz, generally 1-3 cm in diameter, but rarely to 8-10 cm. Elsewhere, the conglomerate is a coarser polymictic roundstone conglomerate, lighter brown in colour and containing pebbles and cobbles (3-15 cm) of grey quartzite, pink rhyolite porphyry, granite and rhyolite (relative percentages approximately 60, 25, 10 and 5 respectively).

Most of the sequence is thickly and massively bedded, coarse grained material, generally lacking obvious sedimentary structures, although weakly developed coarse grading and angular rip-up clasts of reddish siltstone occur locally. Bedding is only clearly determined where interbedded finer grained beds of wacke, sandstone and siltstone occur. Some of these sandstone beds display graded bedding. The sequence as a whole appears to fine upwards.

The section exposed along northeast Framboise River east of Caledonia Road is more complicated than those observed at all other locations. In addition to the typical cover sequence, as described above, there appears to be a quite different facies of clastic rocks, locally intervening between the former sequence and the usual metamorphic basement. Several repetitions, apparently due to folding or faulting or both, further complicate relationships (Fig. 3-1). This intervening facies is principally grey and includes quartz breccia and a polymictic breccia containing angular to subangular clasts of quartz, quartzite, and green and pink phyllite interbedded with quartz grit, wacke, sandstone and siltstone. Age relationships among the latter rocks, the typical cover rock sequence and the metamorphic basement could not be established because of gaps in exposure and common faulting. Smith (1978) apparently included both facies within the lower part of the Kelvin Lake Formation.

In the vicinity of Framboise Intervale, a sequence of clastic rocks located between Capelin Cove Pluton and the metavolcanic basement is poorly exposed in South Brook and the next brook to the south. Neither contact with the adjacent plutonic and metavolcanic rocks is exposed, although a fault contact with the metavolcanic basement to the west is inferred. This clastic sequence has apparently been contact metamorphosed as revealed by its induration and by spotting of its most pelitic members. It consists of recrystallized grey

arkosic grit, sandstone and minor spotted hornfelsed siltstone. Cut-and-fill structures and graded bedding are commonly developed and have survived recrystallization. Conceivably, this sequence was reddish prior to metamorphism, but it is not known if it is the correlative of the red clastic sequence extending from Currie Lake to Framboise River; it was shown by Weeks (1954) as belonging to the Middle River Group. Nor are the source and age of the contact metamorphism known, although it could be postulated that Capelin Cove Pluton, due to its proximity (within 0.5-1 km), is the most likely source. Its apparent radiometric age is 545 ± 28 Ma (Cormier, 1972; Keppie, 1979), implying that any contact aureole rocks would have to be of at least Early Cambrian age.

Age of the Sedimentary Cover Rocks

The red clastic sequence is apparently unfossiliferous so interpretation of its age is dependent upon its stratigraphic relationships with other units. Within the areas mapped in this study it can be shown that the sequence:

(1) unconformably overlies metavolcanic and related rocks of the Stirling belt;

(2) has been deformed into open upright folds trending north-northeast; and

(3) contains well rounded cobbles and pebbles of grey quartzite, pink rhyolite porphyry and granite, in addition to the locally derived metavolcanic clasts.

Evidence for its age is somewhat circumstantial: (1) there are strong lithological similarities to the Lower Cambrian Morrison River and MacCodrum formations outcropping farther to the east and northeast; (2) the contact metamorphosed facies near Framboise Intervale, if within the aureole of the Capelin Cove Pluton, should be of Early Cambrian age.

Some 5 km north of the study areas mapped, this red sequence, there named the Kelvin Lake Formation, was interpreted by Smith (1978) to conformably underlie a fossiliferous sequence of late Early to Middle Cambrian age (Gillis Brook Formation). This implies that the red clastic sequence is of Early Cambrian age and hence that the underlying metavolcanic basement is of Late Precambrian age.

STRUCTURE

DUCTILE DEFORMATION

Minor Structure

Primary volcanic and sedimentary layering is variably developed within the area. Metavolcanic rocks, particularly the quartz-feldspar rhyodacite flows, and lesser andesitic basalts are generally massive, or less commonly flow-brecciated, and mainly devoid of internal layering. Metatuffs commonly display crude compositional banding but this is typically strongly overprinted and hence obscured by schistosity (S_1). Metasedimentary rocks, comprising chert, siltstone, and lesser lithic wacke, show well preserved bedding and other sedimentary structures, but these rocks are mainly restricted to narrow zones, apparently within the cores of large folds. In general, therefore, bedding and primary volcanic layering are sparsely developed and their orientations are variable (Fig. 3-6a) but suggest that folding, mainly about northeast-southwest axes, has occurred. However, there are insufficient data to permit clear deciphering of location, style and geometry of the major structure(s).

In coarser tuffs and volcanic rocks the S_1 foliation ranges from a

very weak microscopic preferred orientation of phyllosilicates through a weak mesoscopic sericitic or chloritic foliation to a well developed schistosity, the latter restricted to narrow zones possibly due to inhomogeneous deformation. In contrast, fine grained tuffaceous units commonly display uniformly pervasive phyllitic schistosity. A cleavage is also ubiquitous in the metasedimentary rocks but is generally weak except in the hinges of minor folds where it approaches a slaty cleavage (e.g. Fig. 3-6b). These S_1 foliations are relatively uniform in orientation, striking northeast and dipping southeast at moderate to steep angles (Fig. 3-6b).

No uniformly oriented second penetrative foliation (S_2) was observed in these rocks although several localized fracture cleavages do occur (Fig. 3-6e). The age of these is uncertain but they could be related to (1) coaxial refolding, (2) northeast-trending, steeply-plunging kink bands and related kink folds (Fig. 3-6c) which occur sporadically throughout the area, or (3) episodes of brittle deformation, as some of the fracture cleavages do parallel important joint and fault directions (Fig. 3-6g, h).

Evidence for a second episode of coaxial folding in the area comes mainly from the unmetamorphosed clastic rocks which unconformably overlie the Stirling metamorphic sequence and are folded into upright open folds plunging northeast at low angles (Fig. 3-6d). As these folds are approximately coaxial with those in the underlying metamorphic rocks, it is possible that the effects of this deformation on the metamorphic rocks were confined to tightening (i.e. further closure) of pre-existing F_1 folds and(or) to inhomogeneously distributed shearing and fracturing. Thus there is evidence from minor structures for perhaps three episodes of tectonic folding having affected the rocks of the Stirling belt:

> D_1 - sparse, open to tight, upright folds with axial planar cleavage or schistosity;
>
> D_2 - upright, open folding of cover rocks, plunging gently northeastward (effects obscured in underlying metamorphic rocks); and
>
> D_3 - sparse kink bands and related folds plunging steeply northeastward (occurring only in thinly bedded or well foliated rocks).

Major Structure

No clear definition of the major structure(s) across the area is possible with the limited structural data available. However, some clues to the large-scale effects of D_1 deformation are provided by the isolated areas of metasedimentary rocks occupying major fold cores in the Caledonia Road area north of Stirling and in the Point Michaud area. In both areas, the folds are upright to slightly overturned, open to close structures plunging at moderate to low angles southwesterly and easterly respectively (Figs. 3-2, 3-7). The plunges of the major folds apparently change along strike, possibly due to differential flattening. Moderately intense cleavage is developed and is crudely axial planar to these large folds.

It is not clear if the metavolcanic and volcaniclastic rocks adjacent to these folded metasedimentary rocks are folded in the same style. No repetition of individual lithological units can be convincingly demonstrated, although it is possible that the quartz-feldspar rhyodacite and related crystal tuffs are repeated (Fig. 3-1).

The unmetamorphosed cover of clastic rocks, folded during the D_2

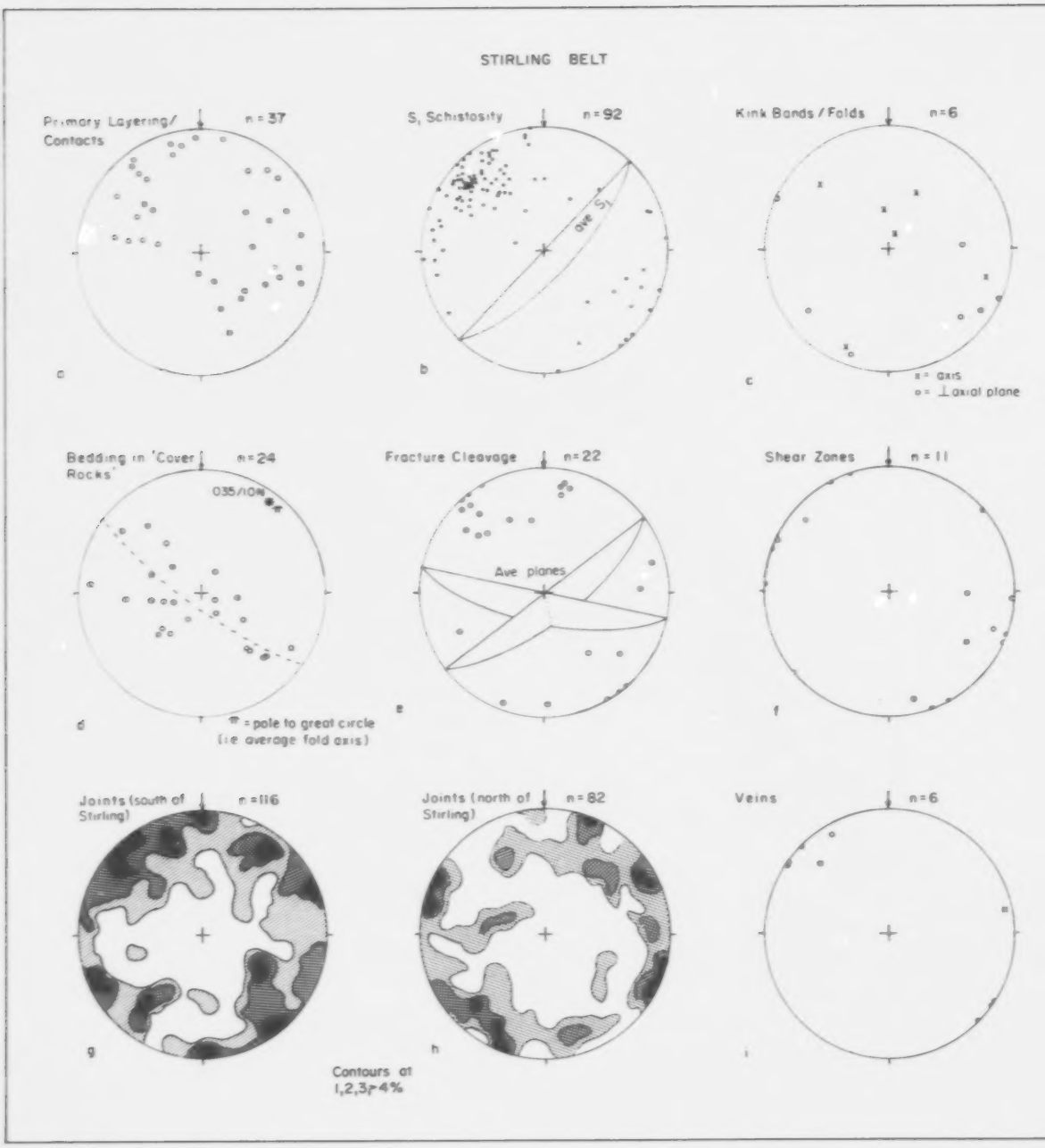


Figure 3-6. Summary of structural data from Stirling belt.

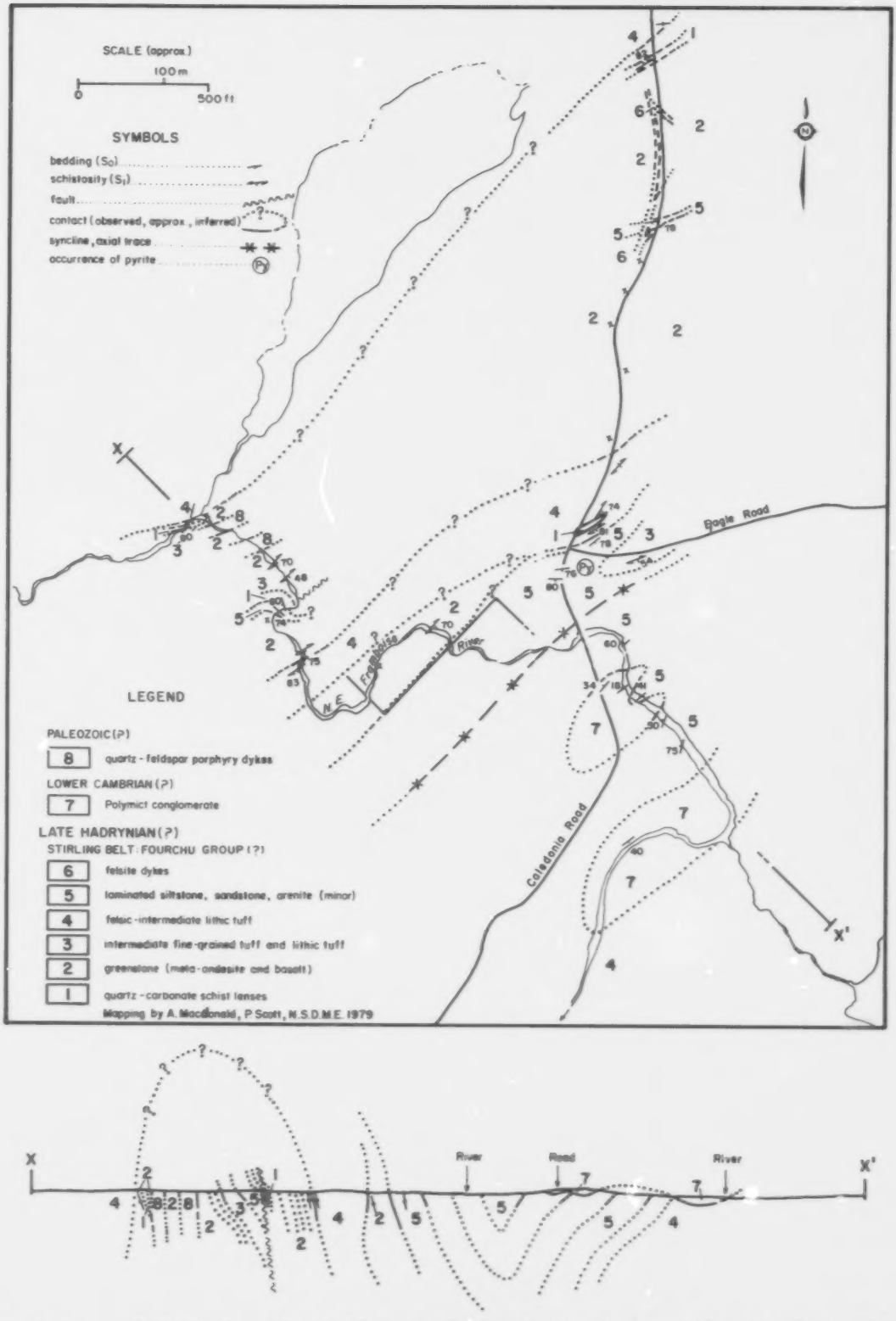


Figure 3-7. Detailed geological map of Caledonia Road pyrite showing, Stirling belt.

deformation, appears to be preserved in small synclines or erosional basins and in a large elongate synclinal trough, in part fault bounded. These synclinal structures are considered to be D_2 major structures but it is not known if the associated faults were formed synchronous with or following this D_2 deformation.

Near the north end of the Capelin Cove Pluton at Framboise Intervale, the clastic cover sequence has been contact metamorphosed, but it is not known whether this thermal overprinting preceded or followed folding.

No large-scale D_3 structures were detected but deviations in strike away from the prevailing northeast-southwest trends which commonly occur could be ascribed to cross folding during a D_3 event, e.g. east-west trends near Point Michaud (Fig. 3-2).

BRITTLE DEFORMATION

Fracture Cleavages

Fracture cleavages are common localized structural features with, in some cases, more than one set developed at a single locality. The majority strike subparallel to the regional S_1 foliation (Fig. 3-6e) and could represent either S_1 or S_2 foliations, especially where developed in competent rocks such as flows. Others crosscut this trend and may be related to one or more of the late-stage more brittle events such as kink folding, faulting and jointing.

Shear Zones

Shear zones are commonly developed within the metamorphic sequence. They generally strike subparallel to regional strike and dip steeply or vertically (Fig. 3-6f). Some of these may in fact represent the response of the metamorphic basement to D_2 folding of the cover rocks. A few cut across the regional trends at high angles and presumably represent a later event.

Joints

Joint patterns, although complex, are relatively consistent along the Stirling belt (Figs. 3-6g, h). Two strong sets of joints subparallel and subperpendicular to the main structural trends (D_1) are dominant, corresponding to longitudinal and cross joints respectively. From the four or five other weaker sets of joints it is possible to infer two apparently conjugate systems with their acute bisectrices (maximum principal stress axes?) oriented approximately north-east-southwest and west-northwest to east-southeast.

Faults

Large-scale faults, subparallel and slightly oblique to the main structural trends, are an important structural feature of the area (Fig. 3-1). They are apparently responsible for the common juxtaposition of metavolcanic and related rocks against unmetamorphosed clastic rocks and possibly also against granitic rocks (e.g. the Capelin Cove Pluton). A strong vertical component of displacement along these faults certainly exists, and it is possible that significant strike-slip displacements have also occurred (cf. Keppie, 1979), but no direct evidence for such displacement was found.

Mapping during this study has shown (Fig. 3-1) that the Stirling Fault may not extend as far southwest as shown by Weeks (1954). Therefore, it is probably a much less important structure than previously considered.

Veins

Three suites of barren veins were recognized:

(1) widespread irregular calcite veinlets and patches;

(2) regular to irregular quartz ± calcite ± epidote veins in intermediate to mafic tuffs and lavas;

(3) local swarms of small quartz-filled tension gashes in metasedimentary rocks.

As the irregular calcite veinlets and patches are commonly found within the large quartz-carbonate lenses, which are a distinctive feature of the Stirling belt, their development is believed to post-date that of the lenses. The same relationship was noted by Miller (1979) in the Mindamar Mine area at Stirling.

The orientations of the few large regular quartz veins which were measured (Fig. 3-6c) were essentially subparallel to the regional strike.

METAMORPHISM

Rocks of the Stirling belt are predominantly low grade metamorphic rocks, locally intruded by granitoid plutons and then elevated to higher grade hornfels, as in the vicinity of the Loch Lomond-Michaelson showings (Fig. 3-8a, b).

Although cleaved, the metasedimentary (epiclastic) rocks do not appear to be metamorphosed, either in outcrop or in hand specimen. In thin section very fine sericite, chlorite and epidote can be detected. The phyllosilicates are aligned parallel to closely spaced cleavage planes. In addition, pressure shadows are commonly developed in the lee of large clastic quartz grains and pyrite cubes.

Similarly, many of the thick volcanic units (rhyodacites, dacites and basaltic andesites) and mafic sheets are not obviously metamorphosed except locally, near gradations into or contacts with tuffaceous units which are in general quite strongly schistose. In these volcanic and volcaniclastic rocks, the common metamorphic minerals include sericite, chlorite, epidote and relatively abundant calcite. Chlorite and epidote are, of course, more abundant in the intermediate to mafic tuffs and lavas and intrusive sheets, and may be accompanied locally by very fine grained tremolite-actinolite and plagioclase. Amygdules in some basaltic andesites consist of zoned aggregates of chlorite, epidote and calcite, rare pumpellyite and zeolites. On the basis of their metamorphic mineralogies, some of these lavas could be considered spilitic and some analyzed samples do plot in the spilitic field of Hughes' (1972) "igneous spectrum" (Fig. 3-9a) and contain 4-5% Na_2O.

The more massive quartz-carbonate bodies consist mainly of granoblastic dolomite, calcite and quartz, whereas the more schistose bodies also contain talc-rich laminae and lenses with or without accessory epidote, chlorite and sericite.

The common assemblages sericite-epidote-calcite and epidote-chlorite-calcite are not diagnostic of any specific low grade metamorphic facies. However, the local occurrences of tremolite-actinolite and of pumpellyite suggest that facies may be transitional between prehnite-pumpellyite facies and greenschist facies (Winkler, 1967).

The appearance of talc in the quartz-carbonate bodies, at low CO_2 partial pressures, would have required T~350-400°C at P=0.2 GPa for formation from magnesite + quartz, and T~400-450°C at the same fluid pressure for formation from dolomite + quartz (Winkler, 1967). Both reactions are compatible with conditions transitional into greenschist facies. Such a low grade of metamorphism might explain the general lack of an obvious penetrative fabric in much of the metamorphic sequence.

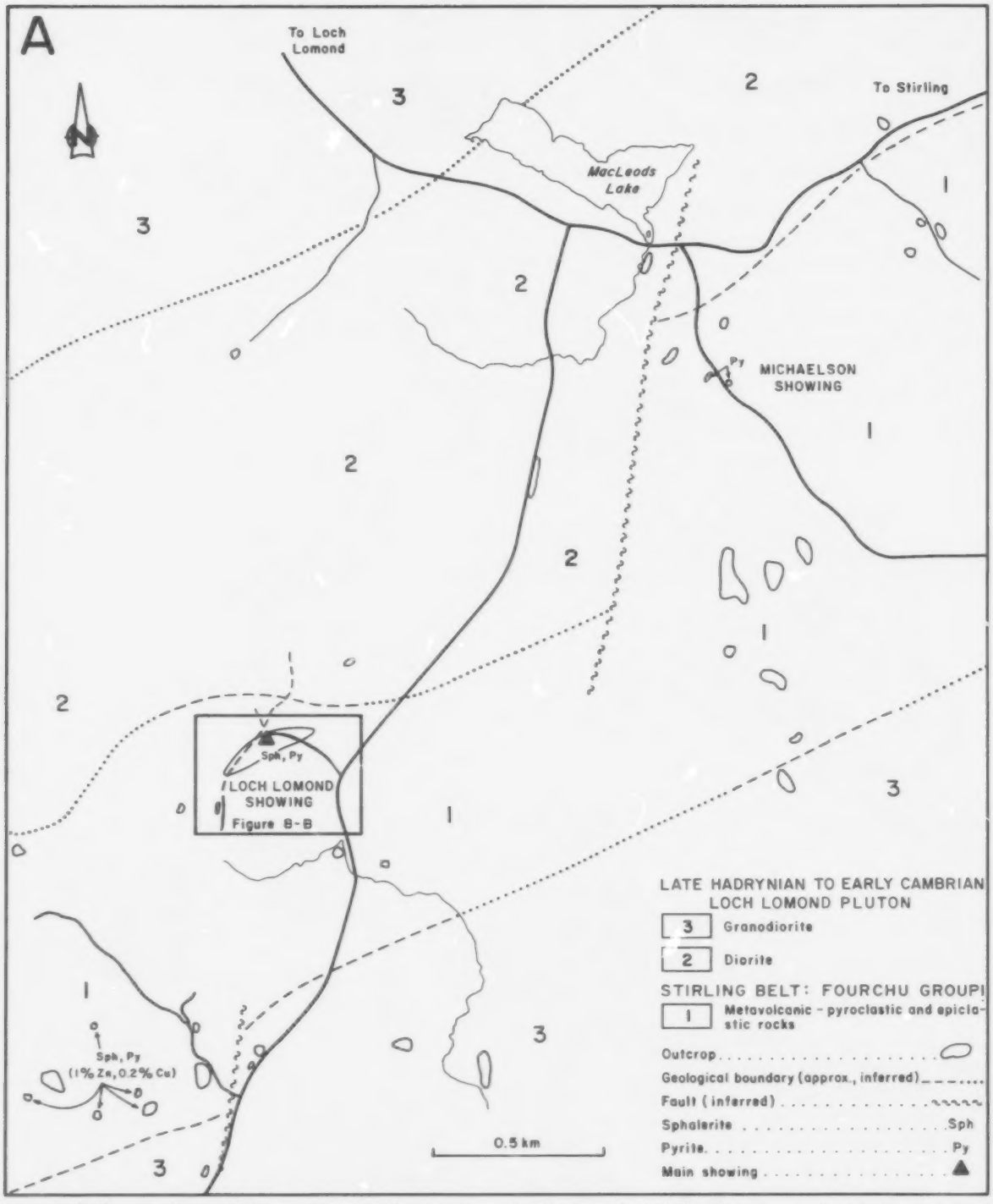
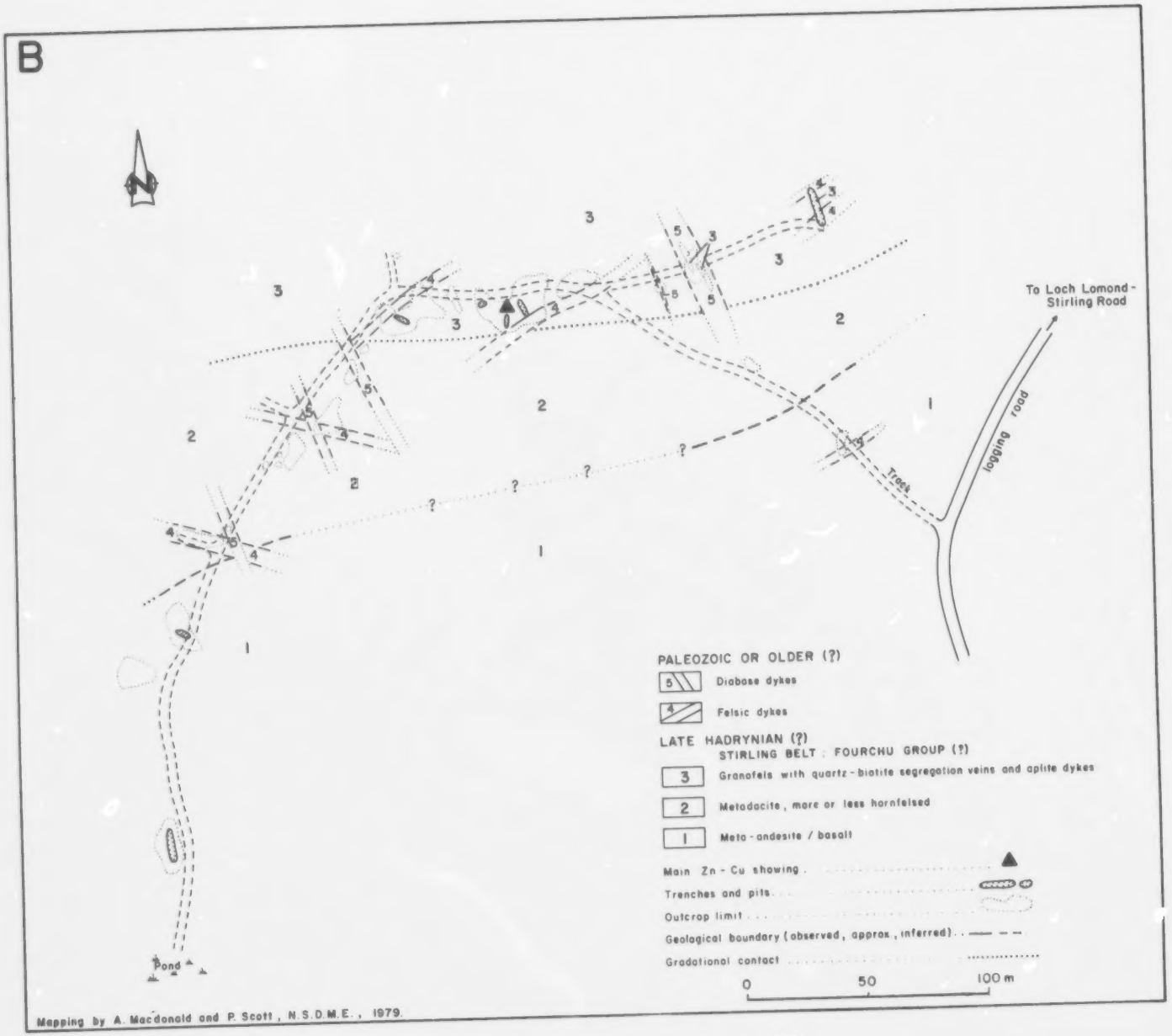


Figure 3-8. a. Location and geological setting of Michaelson and Loch Lomond showings, Stirling belt (after New Jersey Zinc Exploration Limited, 1957).

b. Detailed geological map of Loch Lomond pyrite-sphalerite showing, Stirling belt (over).


B
N
To Loch Lomond - Stirling Road
logging road
Track
Pond
PALEOZOIC OR OLDER (?)
5 Diabase dykes
4 Felsic dykes
LATE HADRYNIAN (?)
STIRLING BELT : FOURCHU GROUP (?)
3 Granofels with quartz - biotite segregation veins and aplite dykes
2 Metadacite, more or less hornfelsed
1 Meta - andesite / basalt
Main Zn - Cu showing
Trenches and pits
Outcrop limit
Geological boundary (observed, approx., inferred)
Gradational contact
0 50 100 m
Mapping by A. Macdonald and P. Scott, N.S.D.M.E., 1979.

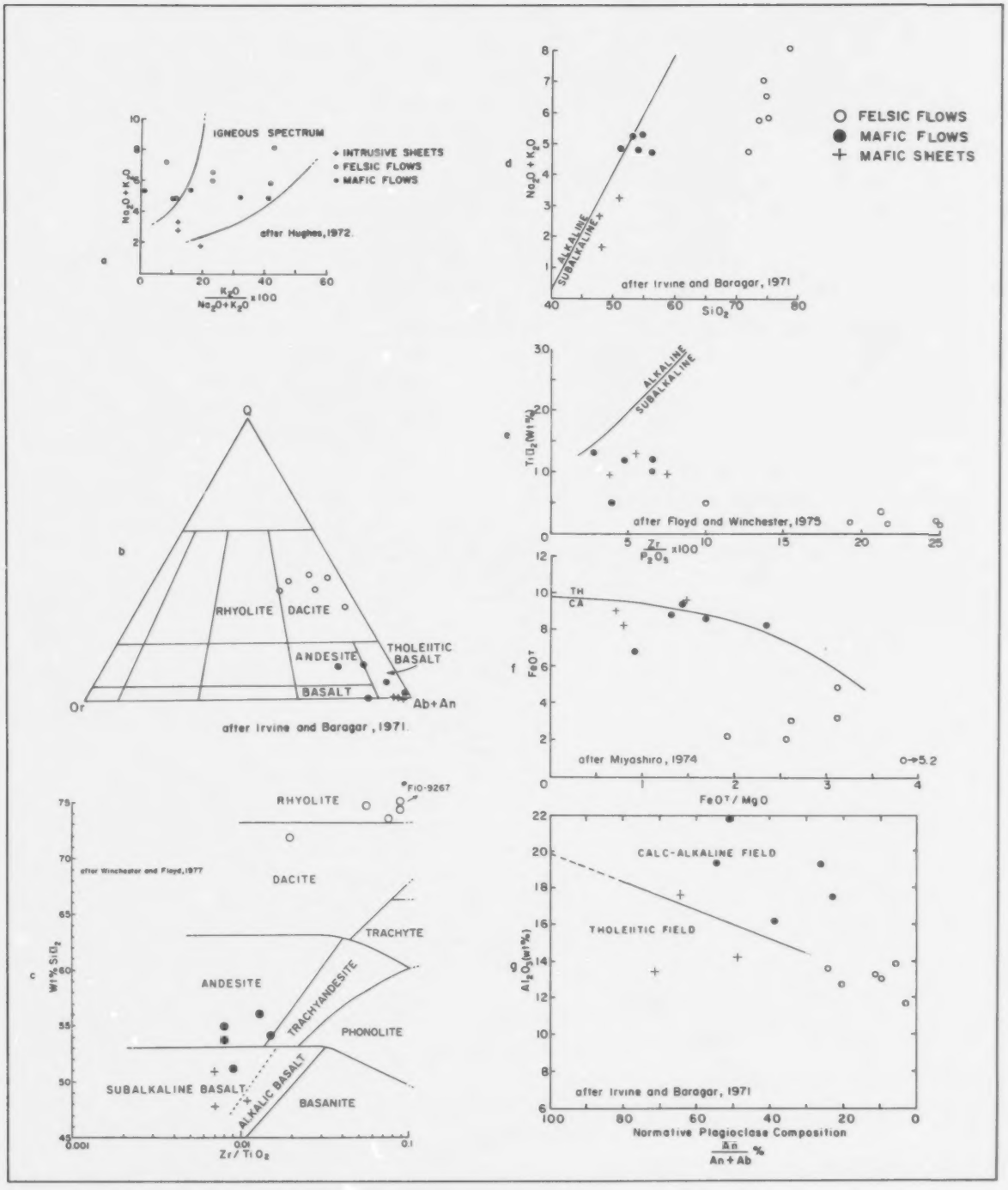


Figure 3-9. Geochemical discrimination plots for Stirling volcanic and related(?) intrusive rocks.

PETROCHEMISTRY OF VOLCANIC AND RELATED INTRUSIVE ROCKS OF THE STIRLING BELT

Samples from 3 mafic sheets, 5 mafic to intermediate flows and 6 felsic flows were analyzed for major oxides and for minor and trace elements (Table 3-1).

As these rocks have undergone low grade metamorphism and variably intense deformation, completely fresh, unaltered rocks are unlikely to have survived. However, only the freshest of available material was selected for analysis. The volatile contents of these rocks are moderately high with the mafic to intermediate rocks containing 1.2-4.3% H_2O and <1.1% CO_2, and the felsic rocks containing 0.7-1.5% H_2O and <0.5% CO_2. The Fe_2O_3/FeO ratios for all the rocks range from 0.1-0.9, with a mean value of 0.4.

When the alkali values are plotted on Hughes' (1972) "igneous spectrum" (Fig. 3-9a), two-thirds of the samples fall within the normal igneous spectrum for Na_2O and K_2O values, while the other one-third falls mainly within the spilitic field.

Based on SiO_2 contents (volatile-free) and on normative quartz - K feldspar - plagioclase proportions (Fig. 3-9b), the volcanic rocks are distinctly bimodal, comprising basalts-andesites and dacites-rhyolites with a silica gap between 57 and 72% and the intrusive sheets are basaltic in composition.

Plotted on (Na_2O+K_2O) vs. SiO_2 and on SiO_2 vs. Zr/TiO_2 and TiO_2 vs. Zr/P_2O_5 diagrams (Figs. 3-9c to e), the samples are seen, especially on the latter, to be distinctly subalkaline. Based on their major oxide chemistry, the specific subalkaline character of these rocks appears to be essentially calc-alkaline for the volcanic rocks and calc-alkaline to tholeiitic for the intrusive sheets, as shown by plots of total FeO vs. total FeO/MgO (Fig. 3-9f), and Al_2O_3 vs. normative plagioclase composition (Fig. 3-9g).

The tectonic setting of the more mafic members (flows and intrusive sheets) can be deduced using discrimination diagrams involving less mobile major oxides such as MgO - total FeO - Al_2O_3 (Pearce et al., 1977) and relatively immobile minor/trace elements such as Zr - Ti - Y (Pearce and Cann, 1973). In the former diagram (Fig. 3-10a), the flows fall essentially within the orogenic field whereas the intrusive sheets fall within the field for ocean-ridge and ocean-floor basalts. However, as noted in Part 2, total FeO and MgO values can be changed as a result of low grade metamorphism (Garcia, 1978) and so may not reliably characterize these rocks. In the latter diagram (Fig. 3-10b), the flows and sheets both fall mainly within the field for calc-alkaline basalts, but overlap into the fields for other types of basalts; no clear distinction between the flows and the sheets can be made on this diagram.

In summary, the volcanic rocks of the Stirling belt appear to be a consistently calc-alkaline suite, presumably generated in an orogenic magmatic arc. However, the flows are distinctly bimodal in composition (as sampled), consisting of basalts to basaltic andesites and dacites to rhyodacites (although pyroclastic rocks of intermediate composition are present). In contrast, the sheets intruding the volcanic rocks appear to be tholeiitic and possibly to have been generated in a different tectonic setting. This suggests that the two suites in this belt, volcanic and intrusive, are not comagmatic.

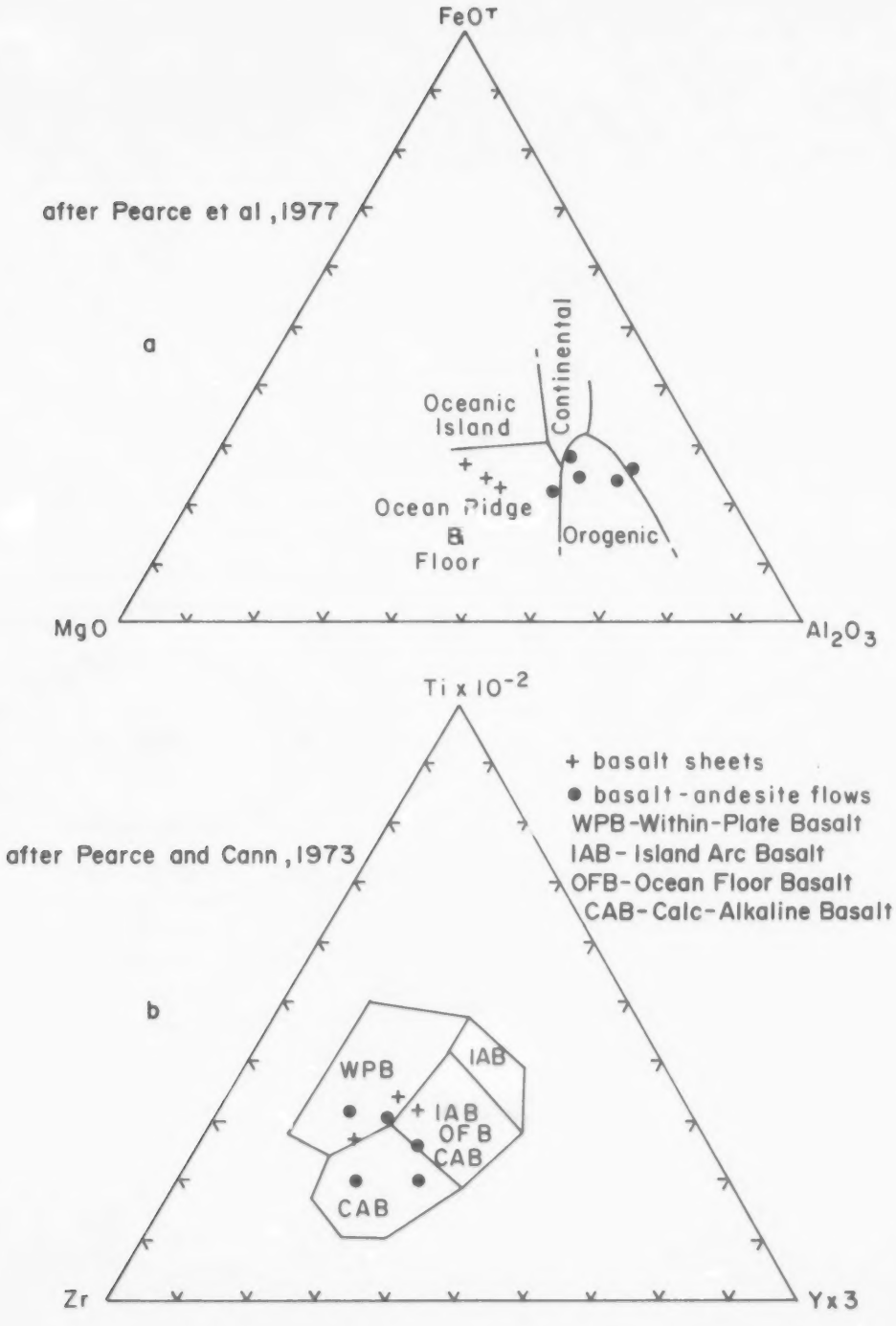


Figure 3-10. Tectonic setting diagrams for Stirling mafic and intrusive rocks.

MINERALIZATION

STIRLING MINE AREA MINERALIZATION

The main occurrence of mineralization and the focus for much of the exploration interest in the area is the now mined-out Mindamar Zn-Pb-Cu sulphide deposit near Stirling. Early workers (Cairnes, 1917; Alcock, 1930; Watson, 1954, 1957) considered this to be an epigenetic replacement deposit. However, later workers (Poole, 1974; Ruitenberg, 1976; Lydon, 1978) suggested that it was actually a volcanogenic massive sulphide deposit (i.e. principally syngenetic) which had been later deformed and metamorphosed. More recently, the geology of this deposit and its environment of deposition have been studied in some detail by Miller (1979) who specified a volcanic exhalative-sedimentary mode of deposition on the flank of a felsic volcanic pile. Closely associated bedded cherts and carbonate rocks were interpreted as chemical precipitates.

Recent exploration efforts have for the most part concentrated on tracing similar favourable depositional environments mainly along strike away from the deposit accompanied by limited soil and stream sediment geochemistry and ground geophysics. Extensive airborne geophysical surveys have also been flown for St. Joseph Explorations Limited in 1975 (Aerodat Limited, 1975) and for Cominco in 1979 (Mosher, 1979) over most of the volcanic belt.

The only recent diamond-drilling has been just east and northeast of the mine area where 4 holes (Fig. 3-4) were drilled by Cominco Limited in 1978 (Miller, 1978). While no massive sulphide bodies were found in these holes, chiefly stratiform pyritic disseminations were intersected in laminated siltstones, tuffaceous sandstones and minor cherts apparently overlying more or less foliated rhyolite flows and flow breccias (possibly including some quartz-feldspar crystal tuffs), together with several layers of schistose calcareous tuff of intermediate composition (Fig. 3-4). The whole sequence has been cut by numerous mafic sheets ranging in thickness from a few cm up to 20 m. Minor concentrations of pyrite, as disseminations, fracture-fillings and rare clasts(?), also occur within the rhyolites, which exhibit local alteration effects variable in both distribution and intensity. The rhyolites are changed from their normal grey to greenish-grey colours to flesh and pink colours and are distinctly more calcareous. In thin section, they are seen to be both sericitized and carbonatized to varying degrees. The sericite is found replacing feldspar phenocrysts and as finely dispersed flakes throughout the groundmass (randomly oriented in the more massive rhyolites, strongly oriented in the more schistose varieties). However, in the most intensely altered varieties, the sericite is also found in localized concentrations. Calcite is ubiquitous in the altered rocks and is found: (1) interstitially within the groundmass, (2) in pressure shadows adjacent to phenocrysts and (3) in crosscutting veinlets. Associated with the sericite and calcite are minor amounts of chlorite and epidote, but the amounts present do not clearly correlate with the intensity of alteration.

No distinct alteration effects were recognized within the epiclastic sequence of sandstones, siltstones and cherts. Although some laminae are distinctly calcareous, they could be of primary sedimentary origin.

Calcite veinlets (with or without quartz) extend through the whole sequence. Locally they create minor stockworks which appear to be spatially associated with areas of chlorite-epidote-calcite alteration in

some of the layers of intermediate tuff and some mafic sheets. However, it has been suggested by Miller (1979) that such vein calcite is distinctly younger than and not directly related to the pervasive carbonate alteration.

OTHER OCCURRENCES OF MINERALIZATION

A number of other occurrences of predominantly pyritic mineralization occur outside of the Stirling area mainly along strike farther northeast and southwest (Fig. 0-1). These can be subdivided into three groups:

(1) massive pyritic lenses/pods occurring at contacts between rhyolite porphyry and bedded tuffs: Marie Joseph Brook and Taylors Brook occurrences (Figs. 3-1 and 3-11);

(2) strata bound to stratiform disseminated pyrite in laminated cherts, siltstones and tuffaceous sandstones (locally associated with carbonate lenses): Caledonia Road (Fig. 3-7), Red Head and Collins Point occurrences (Fig. 3-2); and

(3) coarse disseminated pyrite and sphalerite in volcanic-volcaniclastic rocks metamorphosed by the Loch Lomond granitoid pluton or one of its satellite bodies of diorite: Michaelson and Loch Lomond occurrences, located 6 km west of Stirling (Fig. 3-8).

The first two groups are almost certainly related, but the third group may be of quite different origin (e.g. contact metasomatic).

Although poorly exposed, the massive pyritic lenses/pods appear to be quite small, not exceeding 30 cm in width and several metres in length (Fig. 3-11). In contrast, the disseminations are diffuse zones 1-2 m thick and in excess of 10 m in length marked by obvious patchy limonitic stains. Within these zones, local richer stratiform concentrations a few centimetres thick, which closely follow bedding in the laminated epiclastic host rocks, exist. The disseminations are typically very fine- to fine-grained and contain less than about 10% sulphides by volume. In both types of occurrence, pyrite is the dominant sulphide, other opaque minerals are present only in very minor to trace amounts. Pyrite displays hiatal grain sizes, ranging from extremely fine grained framboidal aggregates, through fine- to coarse- grained subhedral to euhedral crystalline forms (generally cubes, rarely octahedra). The framboids, in places individually deformed and disrupted, tend to be concentrated into lenses, wisps and spongy aggregates, in close spatial association with crystalline pyrite of varied grain sizes (Figs. 3-12a, b). Sphalerite is present in very small amounts in about 30% of the samples, occurring as rare very fine grained framboidal(?) concentrations associated with framboidal pyrite and as fine grained anhedral patches, both isolated and as partial replacements of pyrite cubes. Chalcopyrite is very rare and was recognized only in samples from the Caledonia Road occurrences as fine anhedra associated with framboidal pyrite.

Four reasonably representative samples of this mineralization (three disseminated, one massive) were analyzed by emission spectrography (Table 3-2) and of these, three were found to contain Cu in the range 100-300 ppm, but no Zn or Pb (detection limits 500 ppm and 100 ppm respectively).

The third group of occurrences, represented by the Michaelson and Loch Lomond showings, is located near the southern margin of a diorite satellite

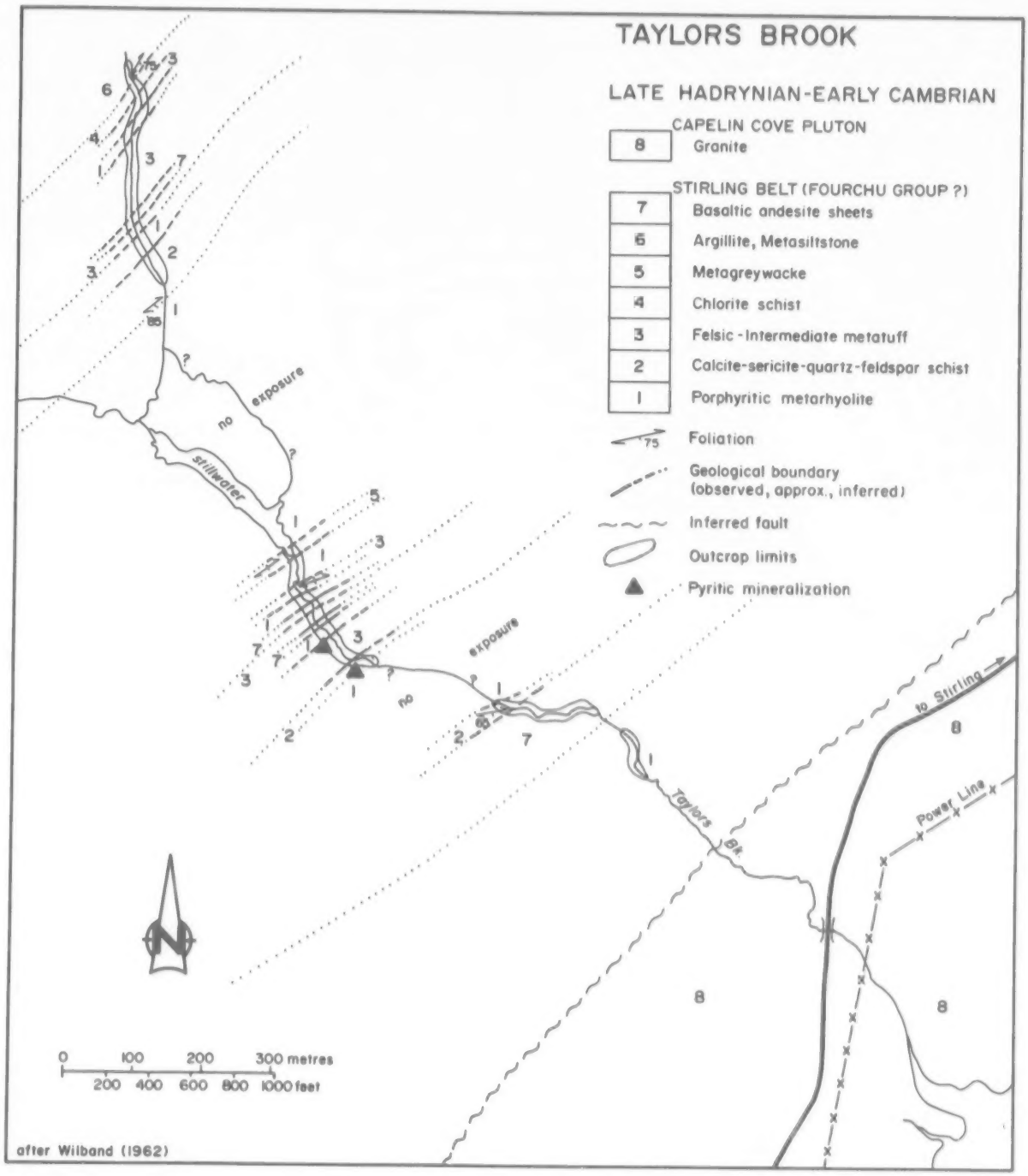


Figure 3-11. Taylors Brook pyrite showing, Stirling belt.

Table 3-2. Results of emission spectrographic scans of selected pyritic mineralization from the Stirling Belt.

Sample	%							
CALEDONIA ROAD:	<.001	.001-.0033	.0033-.01	.01-033	.033-.1	.1-.5	.5-1	≥1
F16-8165B	Be,Yb Ag	Cu,Co	Y,Ni Sc	V,Cr, Zr,Sr	Mn Ba		Ca Ti	Si,Al,Fe Mg,Na
MARIE JOSEPH BROOK:								
F09-8525B	Be,Y Ag,Sc	Yb,Co	(In??),V Cr,Ni	Mo?,Mg Ti,Zr,Cu	Sr		Al	Si,Fe,Ca
RED HEAD - COLLINS POINT:								
F09-8032	Be,Yb Ag	Ni,Co	V,Cr,Y Sc	Zr,Cu Ba,Sr		Ti		Si,Al,Fe Mg,Ca,Na
F09-8040	Be,Yb Ag	Co	V,Cr,Y Ni,Sc,Sr	Zr,Cu Ba		Ti		Si,Al,Fe Mg,Ca,Na
LOCH LOMOND SHOWING:								
F10-5103	Be,Yb Ag,Ni	Cr,Y Co,Ba	Zr,Sc Sr		V	Ca Ti Cu		Si,Al,Fe Mg,Na
F10-8022B	Be,Yb,Ag Ni,Co	Cr	V,Y Sc,Ba	Zr Sr		Cu	Ti	Si,Al,Fe Mg,Ca,Zn
F10-8031B	Be,Yb Y,Ag Ni	Ba	Zr,Co Sc, Sr	Cr Cu	V	Ca Ti		Si,Al,Fe Mg,Na

If not listed above not detected, but if present:

<1%	P, Na
<.1%	As, W, Ta
<.05%	U, Zn
<.033%	Tl, Th, Ce
<.01%	B, Ge, Sb, Nb, In, Pb, Nd, La
<.005%	Mo,Sn,Bi
<.0033	Ga

Laboratory for the Investigation of Minerals

to the Loch Lomond Pluton (Fig. 3-8a). The Michaelson showing consists only of disseminated pyrite, in contrast to the polymineralic Loch Lomond showing which has been more intensively explored. Mineralization at Loch Lomond consists of coarse pyrite and sphalerite with other trace sulphides occurring as patchy disseminations and irregular concentrations within sillimanite-biotite granofels, in turn cut by numerous quartz-biotite segregation veins and small aplite dykes (Fig. 3-8b). Southward the granofels grade into more or less hornfelsed metadacite which is flanked by meta-andesite/ basalt. These rocks are cut by suites of felsite and diabase dykes. The pyrite generally occurs as medium- to coarse-grained cubes and rare octahedra, although grain shapes are lost by impingement in some of the more massive aggregates (Fig. 3-12c). Ilmenite-magnetite occurs as very fine grained anhedral disseminations throughout the rocks and is presumably

mainly primary in origin. Pyrrhotite occurs in very minor amounts as blebs within pyrite, and as rare anhedra either isolated or in contact with chalcopyrite, with which it shows mutually intergrown grain boundaries. Sphalerite occurs in relatively small amounts as fine- to medium-grained anhedral patches, some of which display exsolved (?) blebs of chalcopyrite (Fig. 3-12d). Chalcopyrite is a minor phase occurring as separate fine grained anhedra, anhedral inclusions within pyrite and exsolution blebs within sphalerite.

Three samples from the Loch Lomond occurrence were analyzed by emission spectrography (Table 3-2). All contained detectable Cu, two in the range 0.1-0.5% and the third 100-330 ppm. One sample contained >1% Zn.

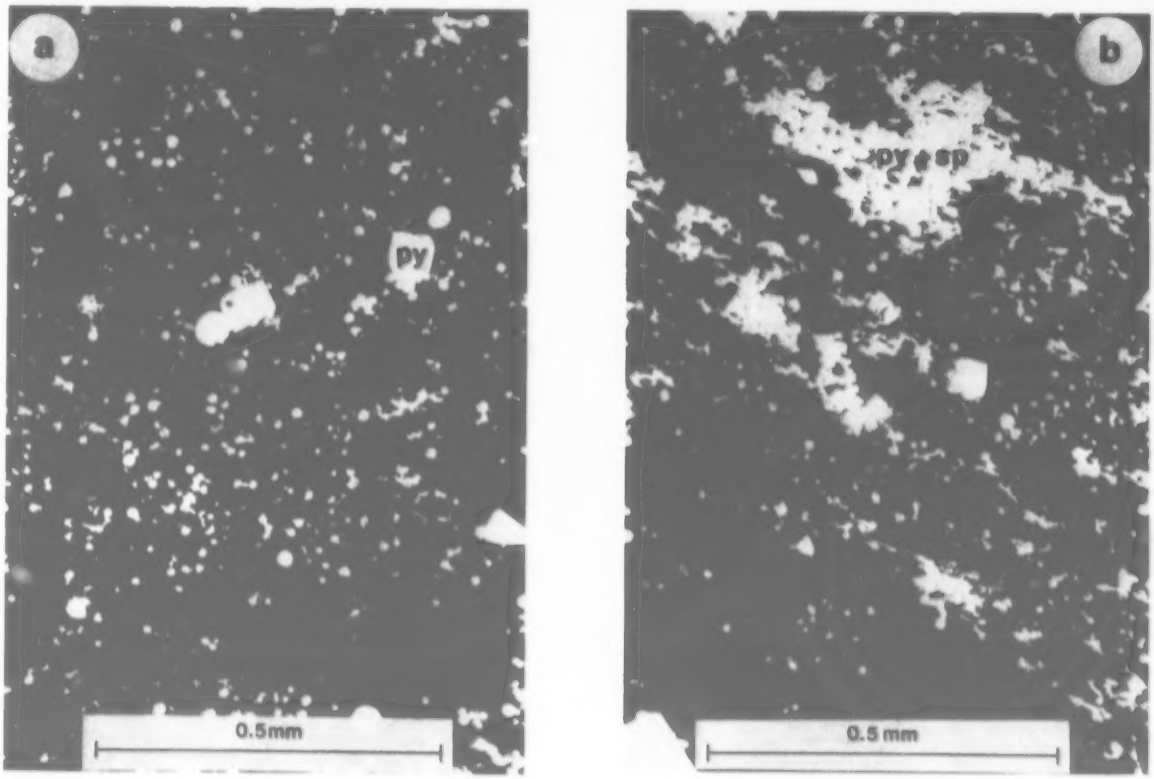
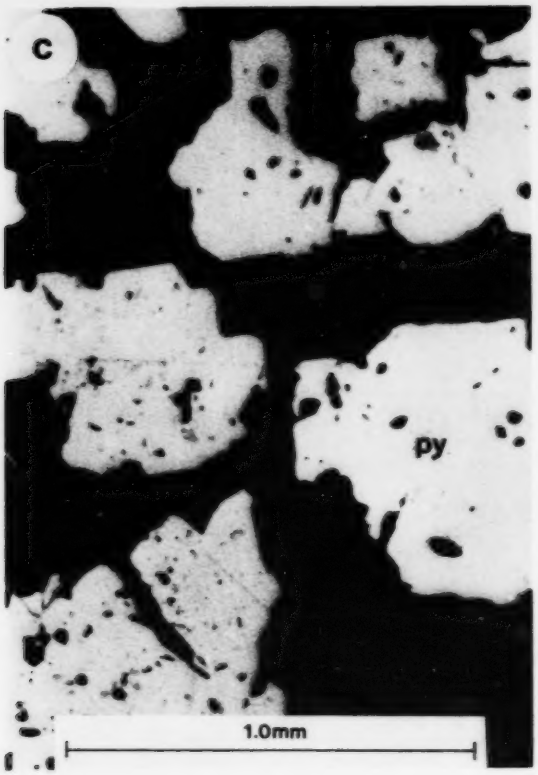


Figure 3-12. Some microscopic features of mineralization in rocks of the Stirling belt (over).

a,b. Fine-grained framboidal pyrite (py) with scattered pyrite cubes. Latter also contains fine anhedral sphalerite (sp). (a. from Collins Point, Point Michaud; b. from Caledonia Road, N. of


c
py
1.0mm

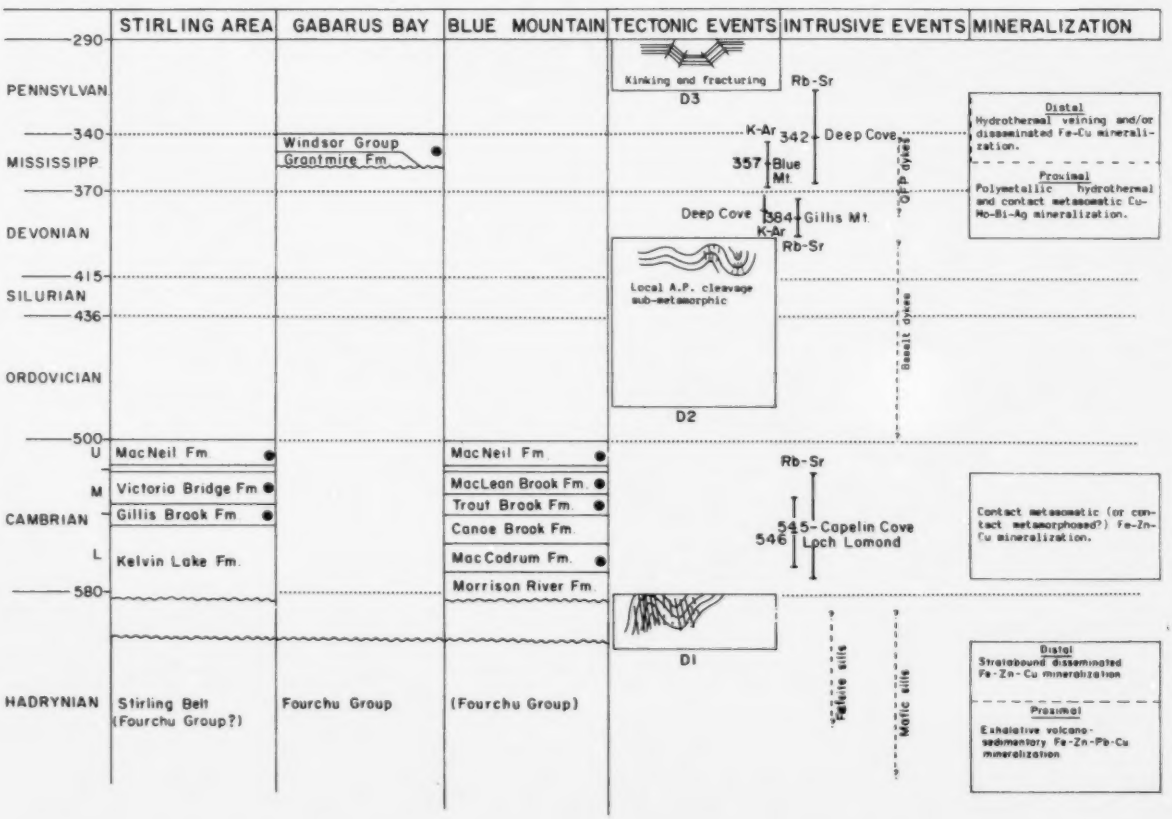
d
cp
py
1.0 mm

PART 4: SUMMARY AND CONCLUSIONS

Stratigraphic, structural and plutonic relationships within and between the areas studied are presented in Table 4-1. These suggest that much of southeastern Cape Breton Island has been affected by: (1) at least three periods of deformation involving folding, (2) at least two periods of granitoid intrusion and (3) at least four episodes of localized metallic sulphide mineralization.

The earliest and most intense tectonic deformation (D_1), which is associated with lower greenschist facies metamorphism, is found only in the Hadrynian(?) mainly volcanic and volcaniclastic rocks of the Fourchu and Stirling belts (believed to be approximate time-equivalent sequences). Direct evidence of the younger, less intense deformations having affected these rocks is generally sporadic and weak. The first period of granitoid intrusion into these rocks appears to have been syn-orogenic to late-orogenic, as represented by the foliated Capelin Cove intrusion and by the unfoliated Loch Lomond composite pluton respectively. Radiometric ages of both the Capelin Cove and Loch Lomond Plutons are, within error limits, principally Cambrian. Yet Lower Cambrian(?) conglomerates in the Stirling area contain distinctive

Table 4-1. Summary and comparison of geological relationships among the three areas studied.



cobbles almost certainly derived from the Loch Lomond Pluton. Therefore, either the intrusions are actually Precambrian in age or the unmetamorphosed clastic cover rocks in the Stirling area are indeed post-Cambrian in age as was originally proposed by Weeks (1954).

Two types of mineralization are associated with the Precambrian-Cambrian(?) crystalline rocks of the area and are apparently restricted to the rocks of the Stirling belt:

(1) exhalative volcano-sedimentary Fe-Zn-Pb-Cu mineralization within or at favourable stratigraphic sequences and interfaces and

(2) contact metasomatic or metamorphosed(?) Fe-Zn-Cu mineralization adjacent to the Loch Lomond Pluton.

Even without considering the Mindamar Zn-Pb-Cu deposit, the relatively common occurrence of stratabound pyritic (Fe-Zn-Cu) mineralization, carbonate precipitates and alteration, and epiclastic rocks within the Stirling belt suggests that the belt has a greater potential for exhalative syngenetic mineralization than the apparently time-equivalent Fourchu belt. In this regard, it is interesting to note that mean Cu and S values (Table 4-2) are consistently higher in volcanic and related intrusive rocks of the Stirling belt than in those of the Fourchu belt. Pyritic occurrences within the Stirling belt are also quite different in character from those within the Fourchu belt which are considered to be much younger epigenetic features.

The second type of pyritic (Fe-Zn-Cu) mineralization occurs locally within rocks of the Stirling belt adjacent to the Loch Lomond Pluton. The mineralization may be genetically related to the pluton, as it occurs within medium to high grade hornfelsed volcanic and volcaniclastic rocks forming a septum between granitic and dioritic phases of the pluton. However, it is also possible that it represents contact metamorphosed volcanogenic mineralization of the first type. Copper mineralization within the pluton itself has been reported from near Enon on the northwest side of the pluton (O'Reilly, 1976). Thus there may be some potential for hydrothermal, contact metasomatic mineralization where such plutons, of apparent Cambrian age, intrude favourable host rocks such as those of the Stirling belt.

The second period of folding (D_2) clearly affected the Cambrian sedimentary succession in the Blue Mountain area, and the sedimentary cover sequence in the Stirling area which has been tentatively assigned to the Lower Cambrian(?) Kelvin Lake Formation (Smith, 1978). Although a weak slaty cleavage is developed in folded pelitic units, this deformation apparently occurred at sub-metamorphic temperatures. While the age of the deformation is not precisely known, it definitely pre-dates intrusion of the Gillis Mountain Pluton (384 $\pm$ 10 Ma; Cormier, 1979) and contact metamorphism in the Blue Mountain area. It is therefore assumed to be of Acadian age, but could conceivably be Taconian.

The third episode of mineralization was intimately associated with intrusion of the small, high-level stocks and plutons of Devono-Carboniferous age, such as Deep Cove, Gillis Mountain and the presumably related body which must underlie the contact aureole at Blue Mountain. This mineralization is of a complex polymetallic type which occurs in two presumably related modes:

(1) in the granitoid rocks at Deep Cove and Gillis Mountain, as disseminated and

Table 4-2. Volcanic rock geochemistry: background values of Cu, Pb, Zn and S.

A. Volcanic Rocks

	MAFIC FLOWS			FELSIC FLOWS		
	Stirling 49-54% SiO_2 n=6	Fourchu 49-56% SiO_2 n=6	Calc-Alkaline Ranges*	Stirling 70-77% SiO_2 n=5	Fourchu 61-70% SiO_2 n=5	Calc-Alkaline Ranges*
	$\bar{x}$ s					
Cu	58 ± 43	26 ± 20	≈100 - 50	18 ± 24	4 ± 3	≈50 - 10
Pb	17 ± 21	9 ± 3	5 - 10	6 ± 4	20 ± 31	10 - 20
Zn	108 ± 52	108 ± 37	100 - 85	48 ± 16	103 ± 25	75 - 40
S	473 ± 701	240 ± 226	≈250	216 ± 211	72 ± 18	260 - 275

* Calc-alkaline ranges from Gribble (1969).

B. Mafic Sheets

	Stirling n=3	Fourchu n=1
	$\bar{x}$	
Cu	86	41
Pb	41	7
Zn	113	150
S	1640	80

vein material closely associated with moderate to intense alteration and

(2) in the country rocks within the contact aureoles at Deep Cove and Blue Mountain, as replacement, disseminated and vein material associated with hybrid metamorphic-metasomatic alteration.

Favourable host rocks for the more distal of these two modes of mineralization appear to be volcanic and volcaniclastic rocks of the Fourchu belt, and calcareous or pyritic horizons within black shales of the Lower to Middle Cambrian sequence. Potential obviously exists for other occurrences of similar mineralization within or adjacent to any other Devono-Carboniferous intrusions which may be identified. Donohoe (1980) has distinquished a number of small granitoid bodies within the Fourchu belt, some of which could be of Devono-Carboniferous age, and Smith (1978) has suggested the existence of several Devono -Carboniferous(?) stocks southwest of the Mira River, where they apparently intruded rocks of the Lower Cambrian(?) Kelvin Lake Formation.

The sporadic minor occurrences of Fe-Cu mineralization, forming vein- and shear-related fillings and disseminations within rocks of the Fourchu belt (e.g. Irish Brook and Gull Cove), although not obviously spatially associated with either Devono-Carboniferous intrusions or their aureoles, could represent dispersed distal mineralization of the same vintage. Certainly, crosscutting quartz-feldspar porphyry dykes, which

petrographically resemble the Deep Cove intrusion, are not uncommon occurrences in the general area of Gabarus Bay. Of course, not all occurrences of pyrite within the Fourchu belt need be of this type, for example common pyrite porphyroblasts within chlorite metatuffs are demonstrably of regional metamorphic origin.

The third period of folding (D_3) is inferred from kink banding and related minor folding which sporadically affect all thinly laminated rocks of the Cambrian cover sequence and its Precambrian metamorphic infrastructure. While the actual age of this deformation has not been established, it is thought to have either accompanied or followed emplacement of the Devono-Carboniferous stocks and plutons. Equally uncertain is the age of the fourth episode of mineralization, except that it was synchronous with or post-dated deposition of Carboniferous strata. It is typically stratabound in nature and although the only known example within the study area is the MacIntyre Lake Cu occurrence in basal Windsor Group rocks, numerous stratabound occurrences of Cu, Pb and Zn in Carboniferous rocks are known from basins farther to the northwest (Kirkham, 1978; Lydon, 1978). While these occurrences have been generally regarded as low temperature syngenetic or diagenetic, some initial studies of geothermometry of stratabound deposits in Carboniferous rocks (Stewart, 1978; Scott, 1980) suggest that more elevated temperatures (up to 300° C?) may be involved, perhaps due to a late thermal event. Such an event could be indirectly related to the younger Devono-Carboniferous plutonism, the youngest radiometric age yet obtained in Cape Breton Island being 330 $\pm$ 23 Ma (Cormier, 1980). However, the potential for this type of mineralization within the study area appears limited due to the restricted distribution of Grantmire Formation and Windsor Group rocks.

COMPARISON OF THE FOURCHU AND STIRLING VOLCANIC BELTS

While there are a number of obvious similarities between the Fourchu and Stirling volcanic belts, some significant differences emerge when the rocks are compared petrologically and geochemically (Table 3-2).

The volcanic rocks of the Fourchu belt are apparently transitional between tholeiitic and calc-alkaline and have a wide compositional range. However, pyroclastic rocks predominate and much of the package appears to have been deposited under subaerial conditions, although minor amounts of epiclastic rocks within the sequence indicate that shallow-water depositional conditions also existed locally. Two suites of intrusive rocks, mafic and felsic, which are ubiquitously associated with the volcanic and pyroclastic rocks appear to be essentially comagmatic in origin and synchronous with the volcanism in their emplacement. The group as a whole, including the intrusive suites, is strongly and pervasively deformed and metamorphosed to lower greenschist facies.

The volcanic rocks of the Stirling belt, in contrast, are apparently uniformly calc-alkaline in character and distinctly bimodal in their compositions. Pyroclastic and volcanic rocks are present in approximately equal proportions. Extensive, locally thick accumulations of epiclastic wackes, siltstones and cherts and common local bodies of carbonate rock within the sequence indicate that depositional conditions were in large part subaqueous, although no pillowed lavas were positively identified. Only one suite of intrusive rocks appears to be intimately associated with the volcanic and other rocks. This is mafic in composition, but distinctly tholeiitic and hence dissimilar to the mafic flows so that contemporaneity

cannot be assumed. The group as a whole, including the mafic intrusive suite, exhibits relatively inhomogeneous deformation, is metamorphosed only up to lowest greenschist facies (prehnite-pumpellyite subfacies of burial metamorphism may be present locally) and is extensively carbonatized. Some of the mafic flows resemble spilites.

Table 4-3. Comparison of the Stirling and Fourchu belts.

ROCK TYPE	%	Stirling Belt	%	Fourchu Belt
VOLCANIC ROCKS	30	Rhyodacite Andesite Basalt CALC-ALKALIC	20	Dacite Andesite Basalt THOLEIITIC TO CALC-ALKALIC
PYROCLASTIC ROCKS	50	Felsic lapilli tuff 25% Intermediate lapilli tuff and ash 75% Predominantly water-lain tuff?	70	Felsic tuff 25% Felsic-intermediate tuff 35% Intermediate-mafic tuff 40% Mainly debris flows and air-fall(?) tuff, minor ash-flows and crystal tuff
EPICLASTIC ROCKS	15	Chert, siltstone and thick volcanic wacke (graded bedding, scour and slump structures common).	5	Volcanic mudstone, siltstone, rare wacke (graded bedding, scour and slump structures)
ASSOCIATED INTRUSIVE ROCKS (FOLIATED)	5	Basalt sheets Dacite sills/sheets(?)	10	Andesite porphyry plugs(?) Dacite sills/sheets Basalt sills/sheets
STRUCTURE		i. S_1 schistosity of variable intensity ii. Sparse kink bands and related folds, and several weak fracture cleavages		i. Penetrative S_1 schistosity ii. Sporadic weak S_2 crenulation cleavage iii. Several sets of kink bands and folds, and related(?) fracture cleavages
METAMORPHIC GRADE		Lowermost greenschist facies (transitional from prehnite-pumpellyite facies?) Extensive carbonatization		Lower greenschist facies (transitional between subfacies quartz-albite-muscovite-chlorite and quartz-albite-epidote-biotite)
YOUNGER INTRUSIVE ROCKS (UNFOLIATED)		Quartz-feldspar and feldspar porphyry Granitoid dykes Basalt dykes(?)		Quartz-feldspar and feldspar porphyry dykes Basalt dykes Gabbro
SYNGENETIC MINERALIZATION		Volcanic exhalative Fe-Zn-Cu mineralization		None identified

REFERENCES

Aerodat Ltd.
1975: Helicopter geophysical survey, Cape Breton Island, Nova Scotia; St. Joseph Explorations Limited; Nova Scotia Department of Mines, Assessment Report 11F/16 07-C-00(01).

Alcock, F. J.
1930: The Stirling zinc property; *in* Zinc and Lead Deposits of Canada; Geological Survey of Canada, Economic Geology Series 8, p. 41-46.

Barr, S. M., O'Reilly, G. A. and O'Beirne, A. M.
1982: Geology and geochemistry of selected granitoid plutons of Cape Breton Island; Nova Scotia Department of Mines and Energy, Paper 82-1, 176 p.

Bingley, J. M.
1969: Louisbourg Project, Cape Breton County, Nova Scotia 1964-1967; Nova Scotia Department of Mines, Open File Report 007.

Bruce, G. S. W.
1969: French Road drilling project: report on 1969 drilling program; copper, French Road, Cape Breton County, Nova Scotia; Dome Exploration Limited; Nova Scotia Department of Mines, Assessment Report 11F/16D 13-C-40(03).

Cairnes, D. D.
1917: Investigations in New Brunswick and Nova Scotia - Stirling zinc- copper-lead deposit, Cape Breton, Nova Scotia; Geological Survey of Canada, Summary Report, 1917, p. 255-260.

Chatterjee, A. K.
1976: Geology and mineralization of Gillis Mountain - Deep Cove area, southeastern Cape Breton; *in* Mineral Resources Division, Report of Activities 1975; Nova Scotia Department of Mines, Report 76-2, p. 96-98.

1977: Massive sulphide mineralization near Blue Mountain, Cape Breton County, southeast Cape Breton; *in* Mineral Resources Division, Report of Activities 1976; Nova Scotia Department of Mines, Report 77-1, p. 71-81.

Cormier, R. F.
1972: Radiometric ages of granitic rocks, Cape Breton Island, Nova Scotia; Canadian Journal of Earth Sciences, v. 9, p. 1074-1086.

1979: Rb/Sr isochron ages of Nova Scotia granitoid plutons; *in* Mineral Resources Division, Report of Activities 1978; Nova Scotia Department of Mines and Energy, Report 79-1, p. 143-147.

1980: New Rb/Sr ages in Nova Scotia; *in* Mineral Resources Division, Report of Activities 1979; Nova Scotia Department of Mines and Energy, Report 80-1, p. 223-234.

Donohoe, H. V.
1980: Fourchu Group studies, southeastern Cape Breton Island; *in* Fourth Annual

Open House and Review of Activities, Program and Summaries, Nova Scotia Department of Mines and Energy, Information Series No. 3, p. 45-48.

Floyd, P. A. and Winchester, J. A.
1975: Magma type and tectonic setting discrimination using immobile elements; Earth and Planetary Science Letters, v. 27, p. 211-218.

Forgeron, F. D.
1974: A summary report on the Gabarus property; molybdenum, Gabarus, Cape Breton County, Nova Scotia; Louisbourg Mines Limited; Nova Scotia Department of Mines, Assessment Report 11F/16A 35-C-41(02).

Garcia, M. O.
1978: Criteria for identification of ancient volcanic arcs; Earth and Planetary Science Letters, v. 14, p. 147-165.

Gribble, C. D.
1969: Distribution of elements in igneous rocks of the normal calc-alkaline sequence; Scottish Journal of Geology, v. 5, p. 322-327.

Hollister, V. F., Potter, R. R. and Barker, A. L.
1974: Porphyry-type deposits of the Appalachian Orogen; Economic Geology, v. 89, p. 618-629.

Hughes, C. J.
1972: Spilites, keratophyres, and the igneous spectrum; Geological Magazine, v. 109, p. 513-527.

Hunter, A. D. and Anderson, E. O.
1975: Report on geological and ground geophysical surveys; zinc, Stirling, Richmond County, Nova Scotia; Cominco Limited; Nova Scotia Department of Mines, Assessment Report 11F/09C 58-0-25-(18).

Hutchinson, R. D.
1952: The stratigraphy and trilobite faunas of the Cambrian sedimentary rocks of Cape Breton Island, Nova Scotia; Geological Survey of Canada, Memoir 263, 124 p.

Irvine, T. N. and Baragar, W. R. A.
1971: A guide to the chemical classification of the common volcanic rocks; Canadian Journal of Earth Sciences, v. 8, p. 523-548.

Keppie, J. D. (Compiler)
1979: Geological map of the Province of Nova Scotia; Nova Scotia Department of Mines and Energy, scale 1:500 000.

Keppie, J. D. and Smith, P. K. (Compilers)
1978: Compilation of isotopic age data of Nova Scotia; Nova Scotia Department of Mines and Energy, Report 78-4, 54 p.

Keppie, J. D., Murphy, B. and Dostal, J.
1979: Petrology of the Late Precambrian Fourchu Group in the Louisbourg area, Cape Breton Island; Nova Scotia Department of Mines and Energy, Paper 79-1, 18 p.

Kirkham, R. V.
1978: Base metal and uranium

distribution along the Windsor-Horton contact, central Cape Breton Island, Nova Scotia; *in* Current Research, Part B, Geological Survey of Canada, Paper 78-1B, p. 121-135.

Kirkham, R. V. and Soregaroli, A. E.
1975: Preliminary assessment of porphyry deposits in the Canadian Appalachians; Geological Survey of Canada, Paper 75-1, Pt. A, p. 249-251.

Leslie, J.
1969: Report on the Gabarus claim group; molybdenum, Gabarus, Cape Breton County, Nova Scotia; Louisbourg Mines Limited; Nova Scotia Department of Mines, Assessment Report 11F/16A 35-C-41(01).

Lydon, J. W.
1978: Observations on some lead-zinc deposits of Nova Scotia; *in* Current Research, Part A, Geological Survey of Canada, Paper 78-1A, p. 293-298.

McNamee, J.
1957: Report on Michaelson groups; zinc, Middle River Framboise, Richmond County, Nova Scotia; New Jersey Zinc Exploration Limited, Nova Scotia Department of Mines, Assessment Report 11F/10D 58-0-14(02).

Miller, C. K.
1978: Report on geological, IP and ground magnetic surveys and drilling; base metals, Stirling, Richmond County, Nova Scotia; Cominco Limited; Nova Scotia Department of Mines and Energy, Assessment Report 11F/16B 07-0-25(01).

1979: The geological setting and environment of ore deposition at the Mindamar Mine, Stirling, Richmond County, Nova Scotia; M.Sc thesis, Dalhousie University, Halifax, Nova Scotia; Nova Scotia Department of Mines and Energy, Thesis 257, 226 p.

Miyashiro, A.
1974: Volcanic rock series in island arcs and active continental margins; American Journal of Science, v. 274, p. 321-355.

Mosher, G. Z.
1979: Report on geological, rock geochemical, airborne EM and magnetic surveys; Stirling, Richmond County, Nova Scotia; Cominco Limited; Nova Scotia Department of Mines and Energy, Assessment Report 11F/16B 07-0-25(02).

Murphy, B.
1977: Preliminary report on part of the Fourchu Group, southeastern Cape Breton Island; *in* Mineral Resources Division, Report of Activities 1976; Nova Scotia Department of Mines, Report 77-1, p. 139-154.

O'Beirne, A. M.
1979: Geology of the Gillis Mountain Pluton, Cape Breton Island, Nova Scotia; M.Sc. thesis, Acadia University,

Wolfville, Nova Scotia; Nova Scotia Department of Mines and Energy, Thesis 280, 68 p.

Oldale, H. R.
1975: Preliminary geological appraisal of the Gabarus Bay area, Cape Breton County, Nova Scotia; Nova Scotia Department of Mines, Open File Report 073.

O'Reilly, G. A.
1977: Field relations and mineral potential of the granitoid rocks of southeast Cape Breton Island; *in* Mineral Resources Division, Report of Activities 1976; Nova Scotia Department of Mines, Report 77-1, p. 81-87.

Pearce, J. A. and Cann, J. R.
1973: Tectonic setting of basic volcanic rocks determined using trace element analysis; Earth and Planetary Science Letters, v. 19, p. 290-300.

Pearce, T. H., Gorman, B. E. and Birkett, T. C.
1977: The relationship between major element chemistry and tectonic environment of basic and intermediate volcanic rocks; Earth and Planetary Science Letters, v. 36, p. 121-132.

Perusse, J.
1960: Report on McIntyre examination; zinc, Middle River Framboise, Richmond County, Nova Scotia; Kennco Explorations Canada Limited; Nova Scotia Department of Mines, Assessment Report 11F/10D 58-0-14(06).

Poole, W. H.
1974: Stratigraphic framework of volcanogenic massive sulphide deposits, Northern Appalachian Orogen; Geological Survey of Canada, Paper 74-1, Part B, p. 11-17.

Riddell, J.
1973: Report on Gabarus property, Louisbourg Option; copper, Gabarus, Cape Breton County, Nova Scotia; United Asbestos Corporation Limited; Nova Scotia Department of Mines, Assessment Report 11F/16A 13-C-41(03).

Roscoe, W. E.
1975: Geological report; zinc, Stirling, Richmond County, Nova Scotia; Cominco Limited; Nova Scotia Department of Mines, Assessment Report 11F/09C 58-0-25(17).

Ruitenberg, A. A.
1976: Comparison of volcanogenic mineral deposits in the northern Appalachians and their relationship to tectonic evolution; *in* Handbook of Strata-bound and Stratiform Ore Deposits; No. 2, Regional Studies and Specific Deposits; Vol. 5 Regional Studies, ed. K. H. Wolf; Elsevier, Amsterdam, p. 109-154

Sangster, A. L.
1977a: Report on diamond-drilling, Lewis Option; base metals, French Road, Cape Breton County, Nova Scotia; St. Joseph Explorations Limited; Nova Scotia Department of Mines,

Assessment Report 11F/16D 07-C-40(05).

1977b: Report on mining claims; base metals, Deep Cove, Cape Breton County, Nova Scotia; St. Joseph Explorations Limited; Nova Scotia Department of Mines, Assessment Report 11F/16D 07-C-31(01).

Scott, P.
1980: Geochemistry and petrography of the Salmon River lead deposit, Cape Breton Island, Nova Scotia; M.Sc. thesis, Acadia University, Wolfville, Nova Scotia; Nova Scotia Department of Mines and Energy, Thesis 458, 190 p.

Smith, P. K.
1978: Geology of the Giant Lake area, southeastern Cape Breton Island; Nova Scotia Department of Mines and Energy, Paper 78-3, 30 p.

Stewart, E.
1978: A study of the lead-zinc mineralization at Jubilee, Victoria County, Nova Scotia; M.Sc. thesis, Acadia University, Wolfville, Nova Scotia; Nova Scotia Department of Mines and Energy, Thesis 355, 111 p.

Watson, K. D.
1954: Paragenesis of the zinc-lead-copper deposits at the Mindamar Mine, Nova Scotia; Economic Geology, v. 49, p. 389-412.

1957: Mindamar Mine, Appalachian region; *in* Structural Geology of Canadian Ore Deposits, v. 2, 6th Commonwealth Mining and Metallurgical Congress, Canada; p. 495-502.

Weeks, L. J.
1954: Southeast Cape Breton Island, Nova Scotia; Geological Survey of Canada, Memoir 277, 112 p.

Wilband, J. T.
1962: The acid volcanic complex of the Bourinot Group, Cape Breton Island, Nova Scotia; M.Sc. thesis, University of New Brunswick, Fredericton, New Brunswick; Nova Scotia Department of Mines and Energy, Thesis 407, 154 p.

Winchester, J. A. and Floyd, P. A.
1977: Geochemical discrimination of different magma series and their differentiation products using immobile elements; Chemical Geology, v. 20, p. 325-343.

Winkler, H. G. F.
1967: Petrogenesis of Metamorphic Rocks (2nd edition); Springer-Verlag, New York, 237 p.

MAPS NOT FILMED

CARTES OMISES